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LARGE CALIBER PROJECTILE SOFT RECOVERY

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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As weapons technology advances and the weapons and projectiles become more sophisticated, more advanced experimental tools and techniques are required. Measurements made of the behavior of the projectile during launch using telemetry techniques can be very expensive unless the instrument package can be recovered and reused. Honeywell, Inc., has designed a projectile soft recovery system for the Ballistic Research Laboratory (BRL) that will accomplish this.

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The apparatus employs a waterscoop mounted to the projectile. The projectile is launched through a band cutter. The projectile then passes through an entrance cone assembly and into the recovery system proper, which consists of a bottom water trough and an overhead, restraining crane rail. This whole assembly is angled slightly by means of five pairs of jacks that cause the projectile to be exposed to increasing depths of water. The waterscoop projects the water forward and imparts sufficient deceleration to the projectile to stop it within the 60-metre length of the system. This system is designed to currently handle three basic projectile calibers: 105-mm, 155-mm, and 203-mm. The deceleration can be held to less than ten percent of the maximum launch acceleration, using this momentum exchange concept.

The system became operational in February 1978 with the test firing of a special, controlled fragmentation warhead for the 155-mm Cannon Launched Guided Projectile (CLGP). In this report, the recovery system is described together with the telemetry and ground stations instrumentation. Representative data are presented.

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I. INTRODUCTION

With the development of projectiles incorporating guidance or sensing systems, the need for apparatus to conduct detailed studies of the dynamic performance of components for these systems has accelerated. One aspect of these studies involves subjecting the mechanical, electronic, or optical components to the full-up gun environment by firing them from a cannon in a suitable carrier. Post-firing diagnostics can then be performed on recovered projectiles which carried these test components.

In the last decade, a variety of techniques have existed or become available for recovering projectiles. There have always existed a number of mechanisms that can be used to recover a projectile with minimal, overall damage during the recovery process. For example, it has been long recognized that firing projectiles vertically, and allowing them to fall back into a plowed dirt recovery field, provides an effective recovery technique. The same approach is equally as effective using coastal waters as the recovery medium. However, there is little control over the linear deceleration loads imposed on the projectile with techniques of this type. If these decelerations or set-forward loads are critical, for whatever reason, suitable apparatus must then be developed wherein some control can be exercised over both the launch and the deceleration trajectories. Numerous types of apparatus were designed to provide for projectile recovery during the last decade. A fairly comprehensive listing of such equipment was made in the early 1970's by Lorraine D. Wright[1].

The Ballistic Research Laboratory (BRL) recognized the potential for such recovery techniques about this time, but the existing apparatus designs did not satisfy all of the projected needs envisioned for such equipment. Primarily, the BRL wanted a projectile recovery system to soft-catch projectiles which were instrumented to measure the interior ballistic environment. Paul G. Baer did a theoretical study of a soft recovery system using a vented cannon and pre-pressurized tube for projectile recovery[2]. While this technique was theoretically sound and could have been translated

[1] *L. D. Wright, "An Investigation of High "g" Launch, Soft-Recovery Test Facilities," Tank Systems Laboratory Technical Report No. RE-TR-71-12, US Army Weapons Command, R&D Directorate, Rock Island, Illinois, March 1973.*

[2] *P. G. Baer, "A Digital Computer Analysis of a 155-mm Soft Recovery System," BRL Report No. 1634, February 1973.* (AD #909014L)

into hardware, it suffered from certain usage deficiencies, most prominent of which was the lack of a multi-caliber capability. The planned BRL system was not directed toward testing a given projectile, but rather was viewed as a device for collecting as much basic interior ballistic data as possible on the Army's major caliber artillery and tank systems. This meant that systems like the Baer pressurized recovery tube, or others with similar characteristics, would have to be built for each caliber: the 105-mm, the 155-mm, and the 203-mm. This was thought to be impractical at the time.

About the time that Wright[1] was completing the 1971 survey, Honeywell, Inc. was successfully using a Ballistic Rail Gun to obtain data on a 155-mm projectile system. This device was being used for their contractual work on the 155-mm Cannon Launched Guided Projectile (CLGP). Soft recovery of this projectile was obtained by attaching a waterscoop to the test projectile and firing the projectile into a water trough, inclined at a small angle to present an ever-increasing depth of water to the advancing projectile. The momentum of the projectile was then transferred to the water ejected forward by the scoop on the projectile. The 30.5-metre long apparatus was judged to be simple and was relatively inexpensive to construct. The potential simplicity, multi-caliber, and short-length characteristics embodied in a device using this principle prompted the BRL to let a contract[3] to Honeywell, Inc., Government and Aeronautical Products Division, to design a system that would have the desired multi-caliber capability.

The design of the Large Caliber Soft Recovery System (LCSRS) and accompanying gun mounting for the 105-mm, M137 Howitzer tube; 105-mm, M68 Gun tube; 155-mm, XM199 Howitzer tube; and 203-mm, M2 Howitzer tube was accomplished under Contract No. DAAD05-73-C-0557. Estimates to build the system as designed proved to be too costly. A reduced scope of work resulted in a construction contract for the recovery section and the gun mount foundation. These and certain other parts of the system were built by the E.J. Alex Construction Company of Boxboro, Massachusetts under Contract DAAD05-76-C-0319. A universal, rigid gun mount was designed for the BRL by S. Andress and G. Lee of the Ordnance Engineering Section, Materiel Test Directorate (MTD), Test and Evaluation Command at the Aberdeen Proving Ground, MD. The mount was fabricated in the MTD machine shops. The following sections of this report will describe the above items and the operation of the system in greater detail.

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[3] *E. J. Halcin, J. A. Pratt, "Design of a Large Caliber Soft-Recovery System for the Ballistic Research Laboratories," BRL Contractor Report No. 308, prepared by Honeywell, Inc., August 1976.* (AD #B013626L)

II. PRINCIPLE OF OPERATION

The deceleration needed for the soft recovery of the projectile is accomplished by converting the impulse of the projectile into the momentum of the water in the trough that is ejected forward on impact. This can be expressed as follows:

$$F_p(\Delta t) = M_w(V_f - V_o) \qquad (1)$$

Where:

F_p = Axial force on the projectile

Δt = Time increment over which the force acts

M_w = Mass of water acted on

V_f = Final velocity of the water

V_o = Initial velocity of the water.

The mass of water ejected forward by the scoop during Δt can be expressed as:

$$M_w = A_w V_p \rho (\Delta t) \qquad (2)$$

Where:

A_w = Cross sectional area of water interacting with the scoop

V_p = Projectile velocity

ρ = Density of water, or water and anti-freeze.

Substitution of Equation (2) into (1) gives:

$$F_p (\Delta t) = A_w V_p \rho (\Delta t)(V_f - V_o)$$

or

$$F_p = A_w V_p \rho (V_f - V_o). \qquad (3)$$

The velocity of the water prior to impact is zero. Water enters the scoop at a velocity equal to that of the projectile. Neglecting the small drag due to the scoop surface, it will exit the scoop at the same velocity. However, the projectile is also moving at that velocity, so that the total exit velocity of the water is twice that of the projectile. Thus:

$$F_p = A_w V_p \rho (2 V_p) = 2\rho A_w V_p^2 . \qquad (4)$$

The differential equation for the motion of the projectile in the water can then be expressed as:

$$M_p \ddot{x} = 2\rho A(x) \dot{x}^2 \qquad (5)$$

Where:

$\ddot{x}$ = Projectile deceleration

M_p = Projectile mass

$\dot{x}$ = Projectile velocity.

$A(x)$ = Cross sectional area of the water contacting the scoop at impact, as a function of projectile displacement.

x = Projectile displacement within the recovery system at the time, t.

The orientation of the projectile in the recovery system illustrating the principle of operation is shown schematically in Figure 1.

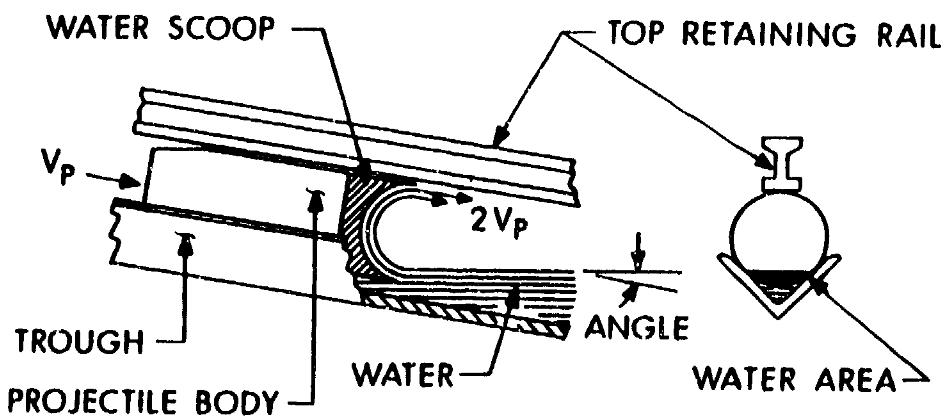
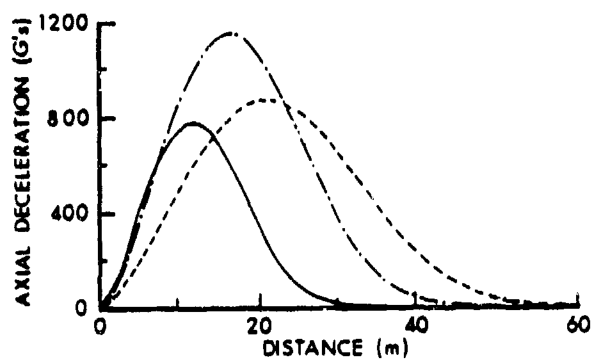


Figure 1. Schematic Showing Principle of Operation

The drag equations described above were used to establish the final overall length of the system and the maximum deceleration limits to conform to design specifications. The decelerations for the family of weapons and projectiles considered during the system design are shown in

the two views of Figure 2. It was a requirement that the system be designed so that the maximum linear and angular deceleration of the projectile during recovery be no greater than 10 percent of the maximum applied acceleration during the launching phase.

HOWITZER	PROJECTILE	PROJECTILE WEIGHT (kg)	FIRING ZONE	MAXIMUM ACCELERATION (G's)	MAXIMUM DECELERATION (G's)	MUZZLE VELOCITY (m/s)
—— 105mm	M1	15.0	7	14,800	777	494
-·—· 155mm	M107	43.1	8	12,020	1,153	684
---- 203mm	M106	90.8	8	9,380	873	671



GUN	PROJECTILE	PROJECTILE WEIGHT (kg)	MAXIMUM ACCELERATION (G's)	MAXIMUM DECELERATION (G's)	MUZZLE VELOCITY (m/s)
105mm	APDS SIM.	5.81	55,900	5,660	1479

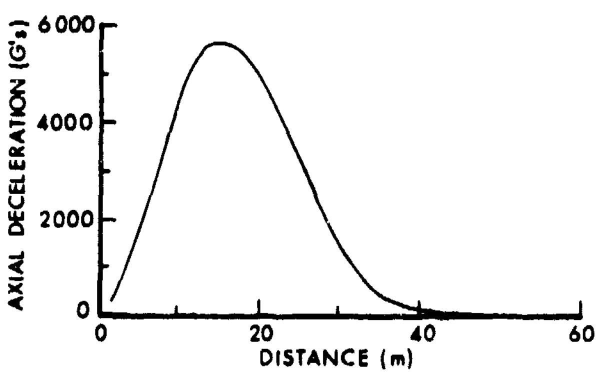


Figure 2. Calculated Design Deceleration Trajectories

III. DESCRIPTION OF THE RECOVERY SYSTEM COMPONENTS

The recovery system consists of several major components some of which are identified in the overall view shown in Figure 3. These consist of the universal rigid gun mount (A), its foundation (B), a rotating band cutter assembly (C), an entrance cone assembly (D), the recovery system proper (E), adjustment jacks and foundations (F), shock absorber (G), hoist (H), and catwalk (I).

A. Universal Rigid Gun Mount

The gun mount was designed to take the trunnion reaction loads of up to 1200 kN of the 203-mm, M201 cannon. Further, the design was made so that either the M3 or M4 series recoil mechanism, or the newer, M158 recoil mechanism could be used with the upper carriage from the 155-mm, M59 Gun or 203-mm, M2 Howitzer set in the trunnion blocks. The centerline of the trunnion was set nominally at 100 cm above the foundation at the fixed system centerline. An Aberdeen Proving Ground, Medium B sleigh with suitable adapters is used to mount all cannons through 155-mm to the upper carriage. The 175-mm and 203-mm size tubes are equipped with their own hoops. The difference between the vertical centerline for each cannon and the system centerline is accounted for by a thick precision shim placed between the base of the mount and a permanently attached steel plate on the foundation. Each position for each cannon is predrilled in the steel foundation plate to match a hole pattern in the mount. Minor position changes for the mount in the horizontal plane are made using the bolts in the brackets shown at the base of the mount. The foundation base plate has been pre-drilled to accept mount locations for the 105-mm, M137 Howitzer tube; 105-mm, M68 Tank Gun; 155-mm, M185 and M199 Howitzer tubes; 203-mm, M2 and M201 Howitzer tubes; and 175-mm, M113 Gun tube. Each gun tube can be elevated up to 170 mils with an elevating mechanism designed for the mount. Thus, the weapon can be fired over the recovery system if required.

B. Rotating Band Cutter Assembly

In order to reduce the severity of balloting that may occur in the recovery system, it is necessary to remove the rifled rotating band material from the projectile body. The band acts as a fulcrum, and the more band material present, the greater the looseness of fit and side-to-side motion about this point. Rotating band material is machined off, just as the projectile emerges from the weapon muzzle, by means of a cutting device designed by Honeywell, Inc. This device, shown in Figure 4, basically consists of twelve tempered-steel teeth evenly spaced in a housing which is bolted to the weapon muzzle.

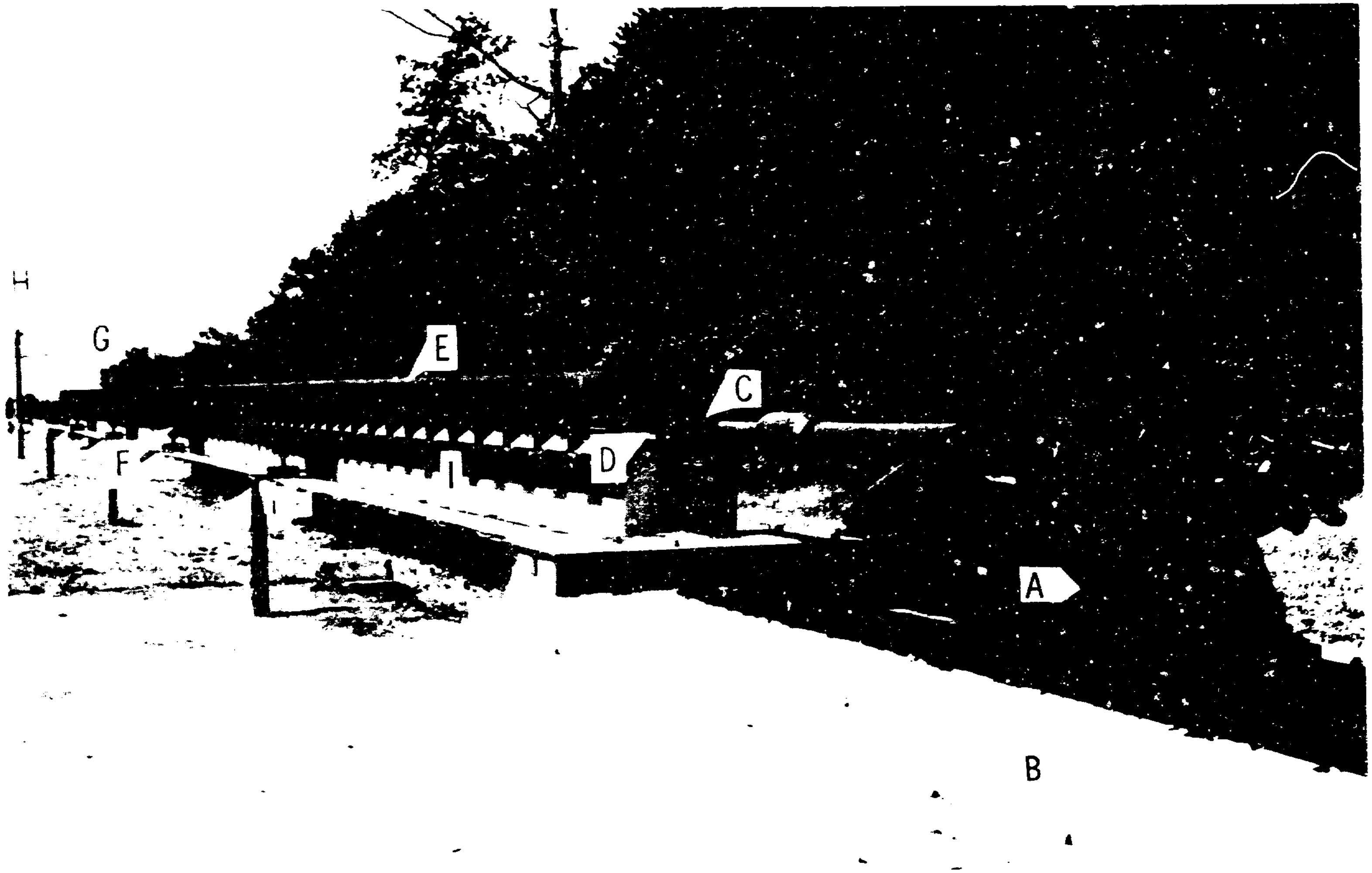


Figure 3. Overall View of the BRL Large Caliber Soft Recovery System

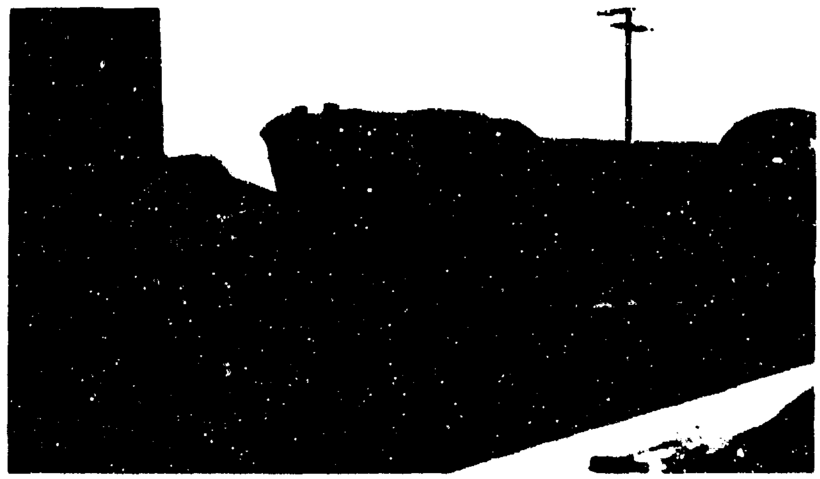


Figure 4. Rotating Band Cutter Assembly

The shape of the individual teeth is shown in the schematic of Figure 5. Dimensions of the teeth are dictated by the caliber of weapons under test, each weapon having its own cutter assembly.

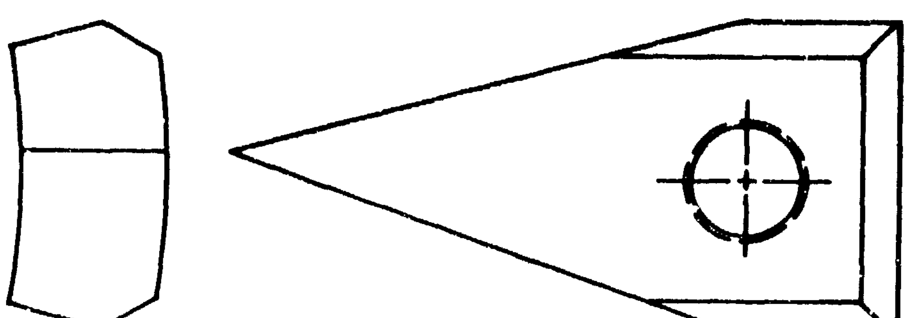


Figure 5. Cutter Teeth

The projection shown on the base of the rotating band cutter assembly attaches to an alignment pin which keeps the tube positioned during projectile in-bore travel. The pin rides in the slotted fixture shown in Figure 6. Suitable space is available for shims during final alignment.

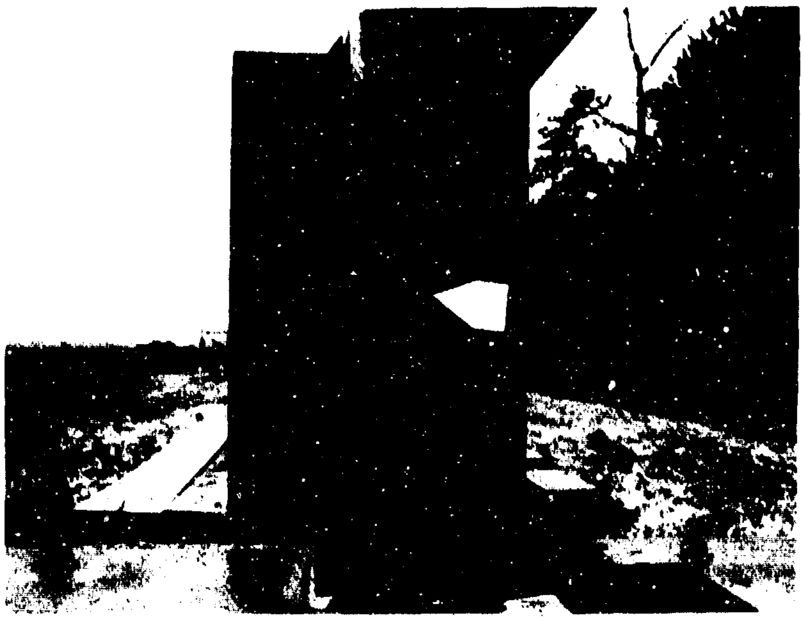


Figure 6. Alignment Pin

C. Entrance Cone Assembly

Following the de-banding operation, the projectile moves into the entrance cone assembly (Figure 7) which helps center the projectile as it finally enters the recovery system water trough. The heavy weldment consists of a fore and aft mounting plate and three, tapered, guide rails positioned to center the projectile on the centerline of the water trough and overhead restraining rail. An individual entrance cone assembly exists for each caliber of weapon to be used with this system.

D. Recovery Section Assembly

The recovery section proper is an all-steel structure fabricated from off-the-shelf commercial materials. The complete structure is shown in Figure 3 and is made up of the following major components: main support beam, uprights, water trough, guide rail, crossbar angles, jacks, and angle iron tie bars. These elements are detailed in the drawing as shown in Figure 8.

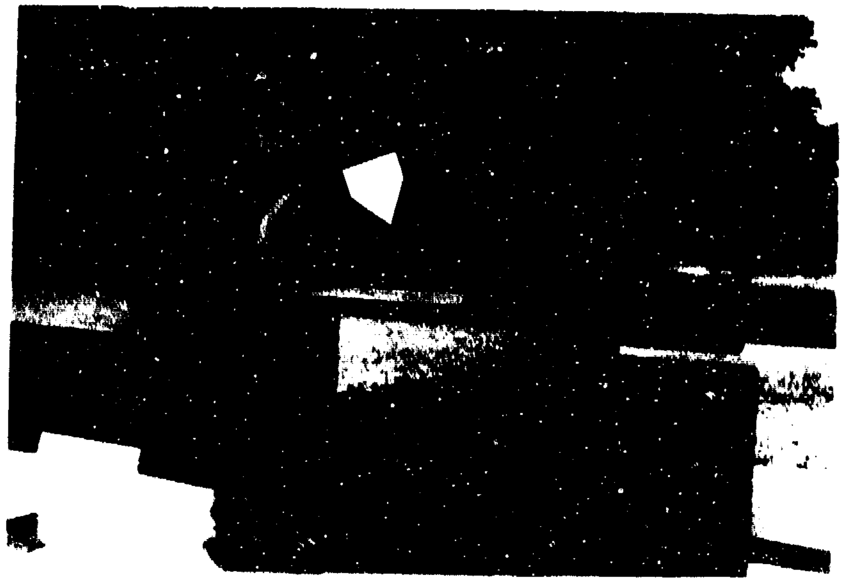


Figure 7. Entrance Cone Assembly

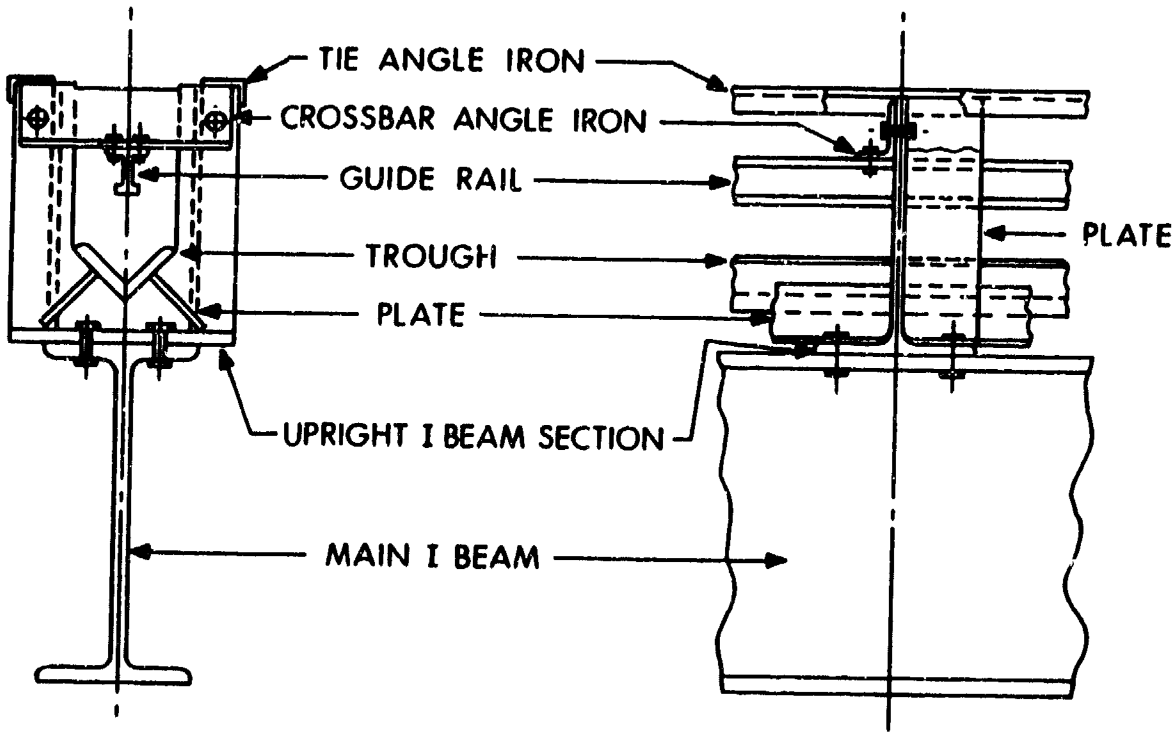


Figure 8. Cross-Sectional View of Recovery Section at Upright

There are five I beams, 12 metres long that are bolted and welded together to make up the 60-metre length of the system. This 91 x 42 x 2.5 cm beam supports sixty-four vertical members made by removing the top flange of the same I beam material. For the first 9 metres of the system, the uprights are spaced about one metre apart. For the next 24 metres, this spacing is reduced to 83 cm, because this is the region of greatest loading. Between the 33.5- and 46.6-metre position, the uprights are again set one metre apart, followed by the remaining stations spaced at 152 cm. All of the uprights are secured to the top flange of the I beam by two bolts in both the forward and aft sections of the base flange. Each upright is cut to receive the 20 x 20 x 2.5 cm angle iron that makes up the water trough and the bottom restraining support for the projectile when in the system. Additional support for the uprights is achieved by welding a 20 x 68 x 2 cm plate on the aft side and perpendicular to the upright between the base flange and the top. The trough is supported by adding 20 x 2 cm plate welded perpendicular to the outside faces of the angle. The uprights are drilled with three sets of holes spaced to conform with the setting of the railroad-track-type guide rail when positioned for either the 105-mm, 155-mm, or 203-mm caliber projectile. The guide rail is bolted to 18 x 10 x 2.2 cm crossbar angle irons which anchor it at the appropriate height for a given caliber. Fine adjustment in the fit between the guide rail and the projectile is obtained by shimming between the crossbars and the rail or milling the crossbar faces.

A cross section of the system at the jack positions is shown in Figure 9. Two Joyce Cridland, 20-ton (18160-kg), worm-gear screw jacks are located on each of five concrete foundations spaced 12 metres apart. The total recovery section rests on the jack supports at these locations. Further support is provided by a 35-ton (31780-kg) Joyce Cridland jack at a clevis/pin juncture that ties the recovery section to the gun mount foundation.

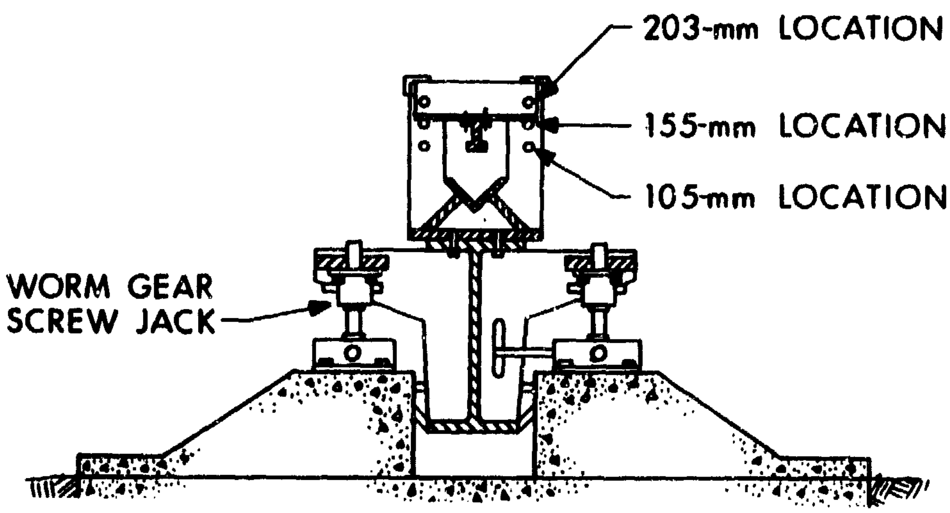


Figure 9. Cross-Sectional View of the Recovery Section at the Jacks

Each jack is supported by a 7.6-cm diameter pin whose axis is parallel to the long axis of the recovery system. This is shown in the two views of Figure 10.

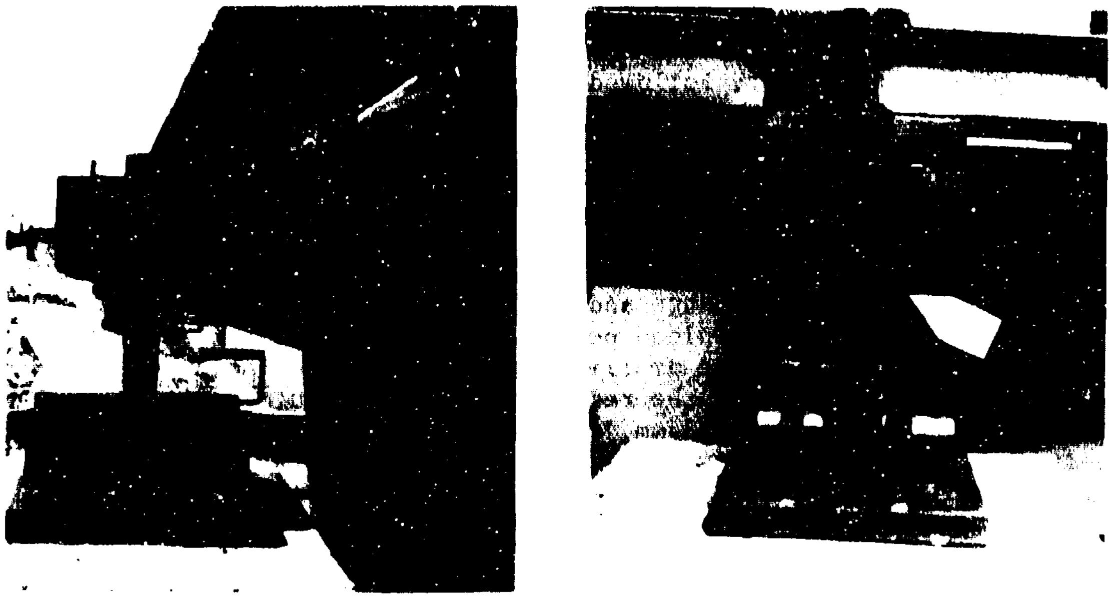
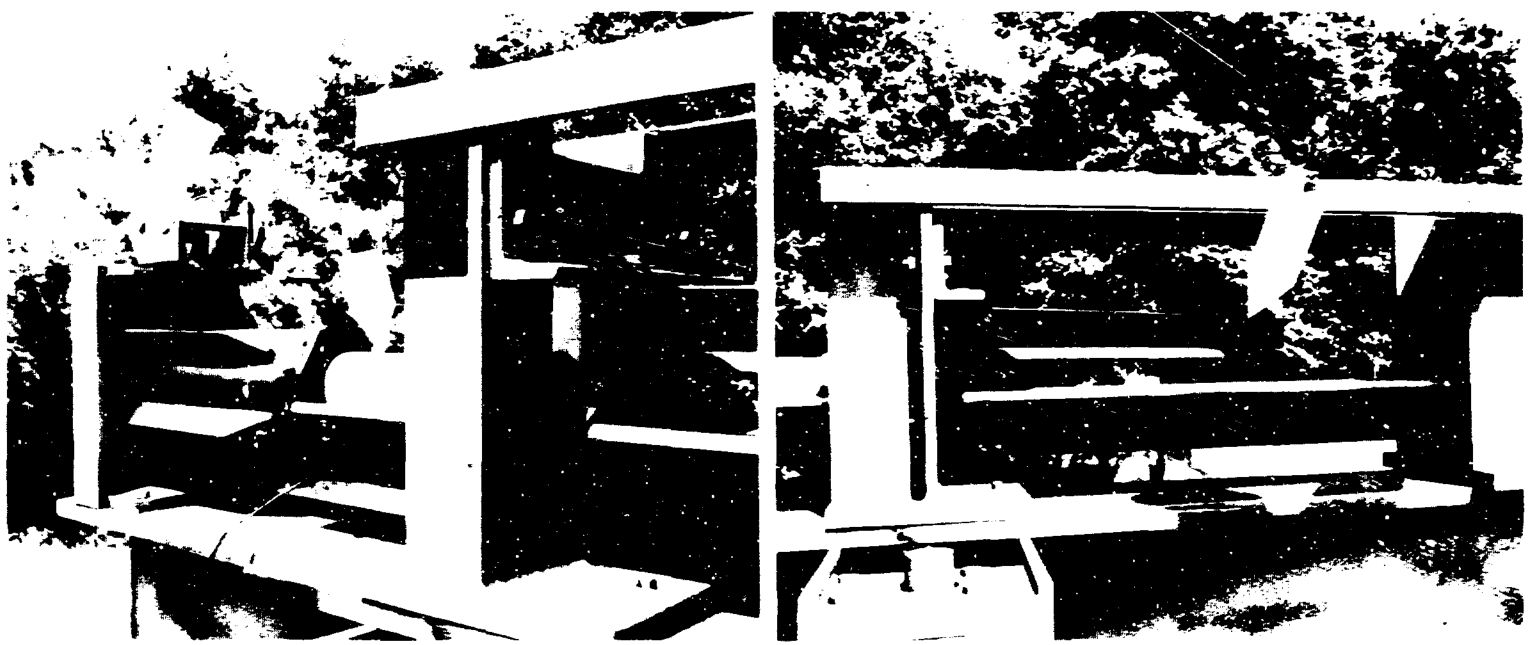


Figure 10. Adjustment Jacks

This arrangement allows the whole system to expand and contract along this surface during extreme temperature changes. The pin also acts as an axle around which the jacks can tilt to provide slight lateral adjustments to the alignment of the trough, if required. A sway bar is attached to the left-hand jack position to help maintain the gross location during these tilting operations.

While the recovery system was held to a 60-metre length, and most of the projectiles could be launched and recovered in that length, under some extreme conditions there would be some residual momentum of the projectile to account for. Therefore, a specially designed shock absorber was added at the end of the recovery section that would be capable of absorbing the momentum of a 90.7-kg projectile traveling at 30.5 m/s. This device is shown in Figure 11A. The face of the piston of the shock absorber is protected from damage from the scoop by inserting a neoprene bumper or other, suitable, semi-soft material at the interface.

An overhead crane is located at the end of the system to facilitate removal of heavy projectiles, such as the 203-mm which weighs 90.7 kg. A winch is also available to help pull projectiles to the end of the recovery system should they rebound from the shock absorber. A removable



(A) (B)

Figure 11. Apparatus at the Terminal End of the Recovery Section

section in the overhead guide rail between the last two stations permits ready removal of the test projectile after firing (Figure 11B). A wooden walkway extends along both sides of the recovery section for its entire length for easy access to all parts of the system. Convenient waterproof electrical outlets are also available along the entire length of the system for the use of power driven tools needed for assembly and disassembly of the overhead guide rail.

IV. SYSTEM PRE-FIRING ALIGNMENT

An optical alignment telescope set in a precision adapter for the particular weapon caliber, is mounted in the test weapon chamber. A suitable target, designed by Honeywell, Inc., for each caliber, is placed at various positions along the trough to measure both horizontal and vertical alignment of the target centerline with that of the weapon. The jacks at each position along the recovery system are manipulated to achieve the desired alignment. The inclination angle of the trough is achieved by measuring the height of the fluid in the trough on the target face. These measurements must conform to the heights calculated for the trough angle used in determining the deceleration profile for the projectile under test. The individual targets are also equipped with precision dial gages so that the space between the trough and the overhead guide rail can be set to the required tolerances. A cylindrical billet representative of the test projectile is also passed along the entire length of the trough system and used in conjunction with feeler gages to make certain that the rail is within 0.5 to 1.5 mm of the desired dimension for the caliber used. Shims are used throughout the system to achieve all of the fine adjustments.

V. INSTRUMENTED TEST PROJECTILE

A decision was reached wherein the initial testing of the soft recovery system would be accomplished and, in addition, useful data on an experimental warhead would be provided. The test vehicle selected was a Type T, 155-mm CLGP warhead body[4] fitted with a water-scoop, end closure assembly and telemetry instrument package. The measurements made using this vehicle were considered to be typical of those required for routine use of the recovery system at this stage of development.

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[4] *C. R. Hargraves, "Metallurgical Control of Fragmentation, Phase II," BRL Contractor Report No. 350, prepared by Honeywell, Inc., September 1977.* (AD #B022333L)

The metal parts of the test projectile, exclusive of the warhead, were designed or modified for these tests at the BRL. A schematic diagram indicating the location of the various parts of the test projectile is shown in Figure 12. A picture of the projectile, broken down into its component parts, is shown in Figure 13A, and an end-on view of the assembled projectile looking into the scoop with an antenna mounted, is shown in Figure 13B. In the photo, the 155-mm Type T, CLGP, warhead is identified as A; B is the scoop assembly; C, the plastic bourrelet; D, the plastic obturator band; E, the gage housing; and F, the base cap. The antenna is identified as Item G in the accompanying view.

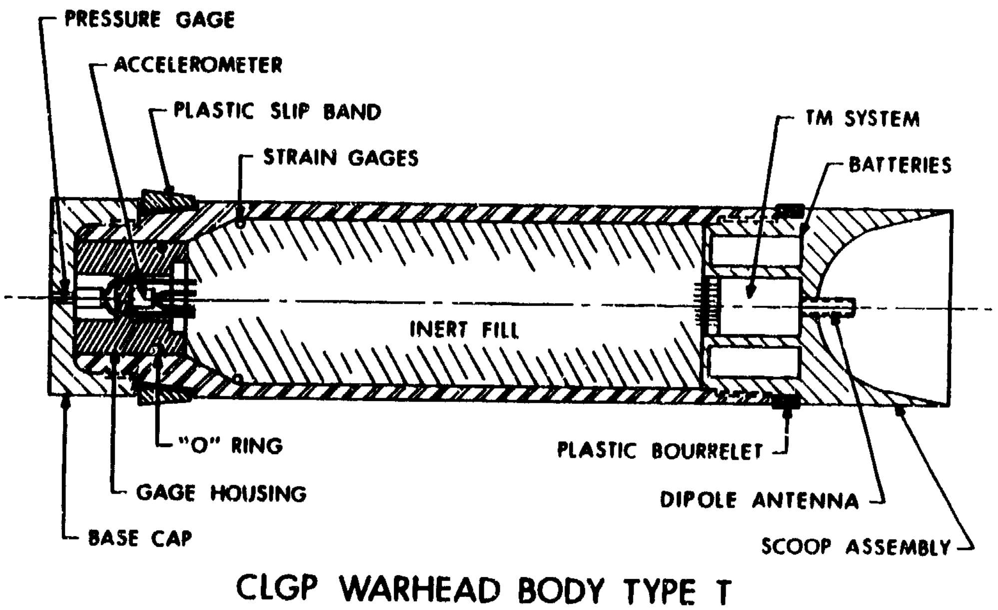
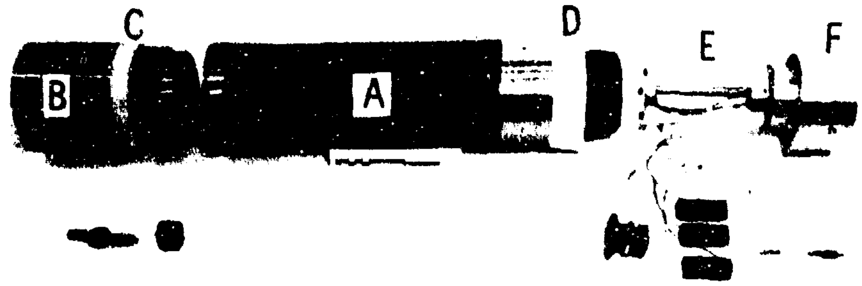
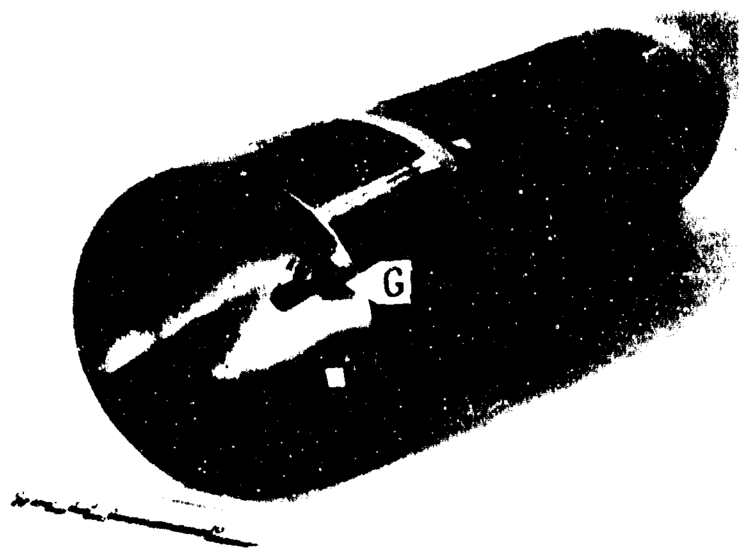


Figure 12. CLGP Warhead Schematic

A reusable proof projectile was designed and fabricated as a backup test vehicle. This projectile had the same general external design and weight of the CLGP round. A schematic diagram of the proof projectile is shown in Figure 14.



(A)



(B)

Figure 13. CLGP Warhead Components and Assembled Unit

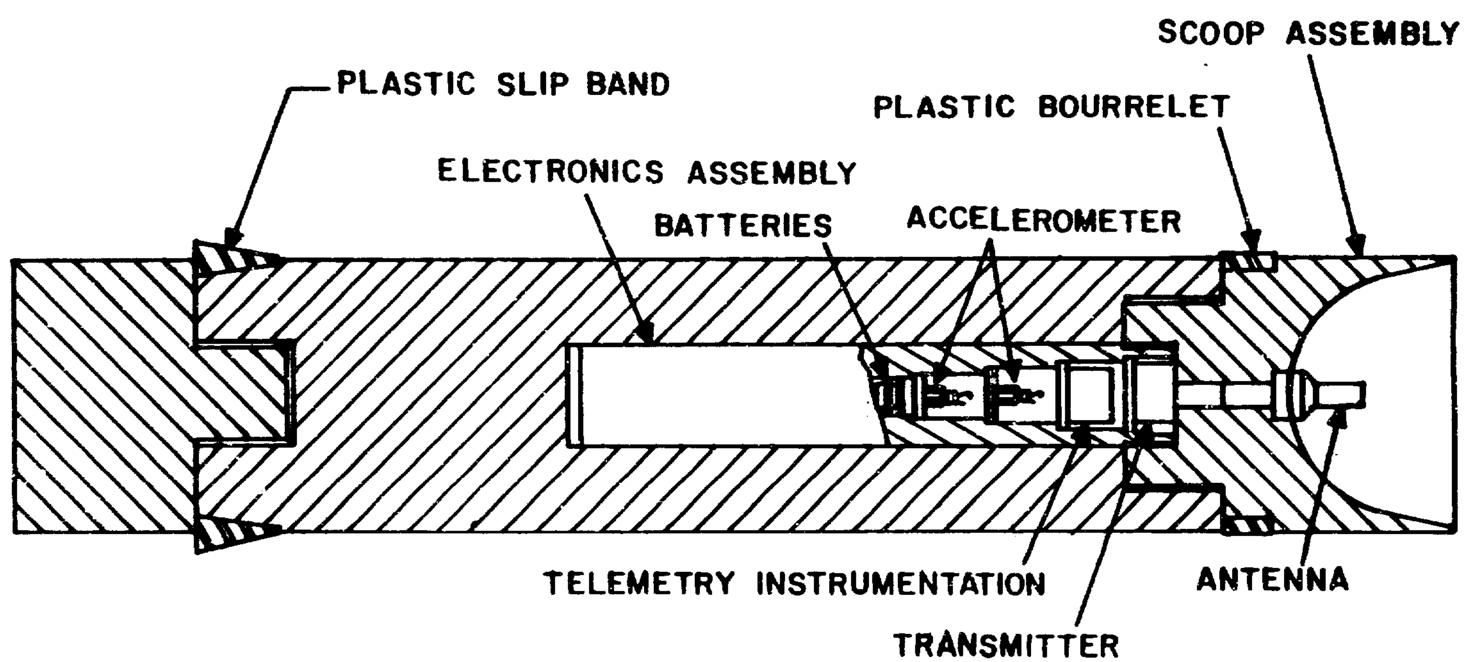


Figure 14. Proof Projectile Schematic

Since it did not require an epoxy potting compound to fill a large internal cavity as in the CLGP round, disassembly and assembly between firings was much faster. When fully assembled, the test projectile weighed 51.9 kg. The calculated deceleration profiles, determined from the water drag equation, are plotted in Figure 15 for the theoretical launch velocities for this weight of test projectile and a trough inclination of 1.20 mils.

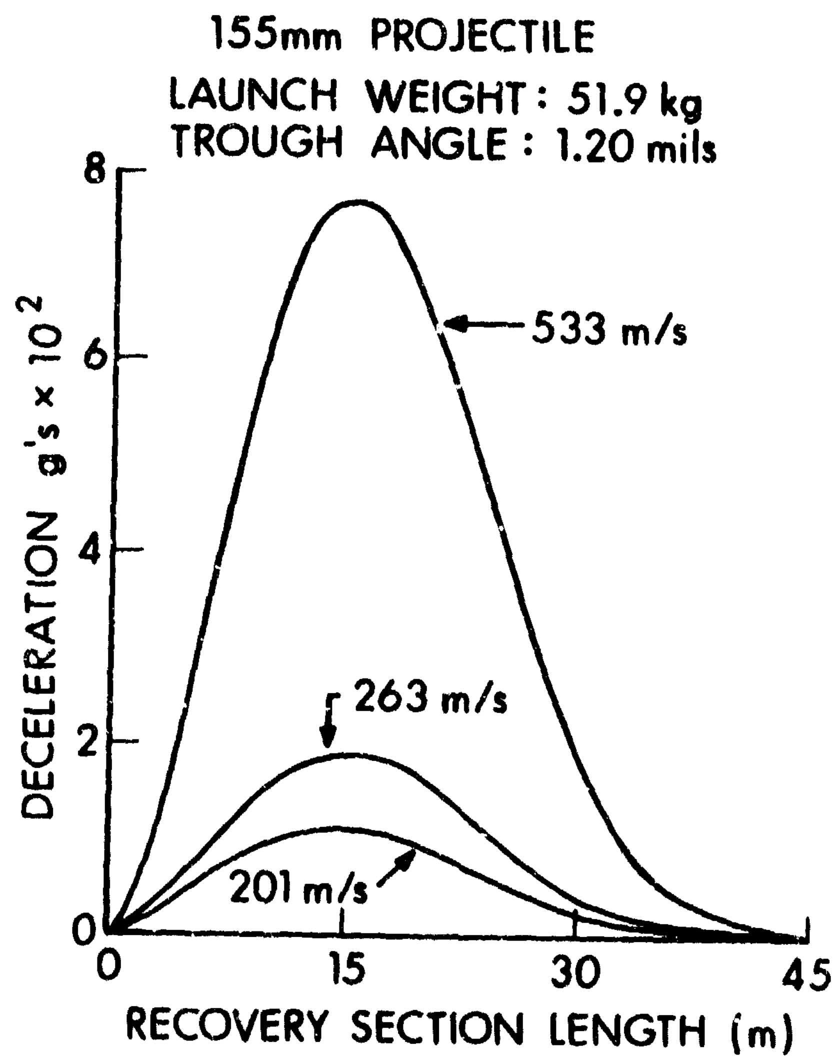


Figure 15. Calculated Decelerations

VI. TRANSMITTING TELEMETRY SYSTEM

The CLGP telemetry system was designed to provide continuous measurement of four performance parameters onboard the projectile during the in-bore phase of its launch trajectory: projectile base pressure, linear acceleration and axial strain at two locations on the inner wall of the warhead. These latter measurements were at points under and between zones of varying metallic hardness.

Instrumentation for the CLGP telemetry transmitting system consisted of a dipole antenna, S-band transmitter, four voltage controlled oscillators (VCO) and three battery packs. The VCOs were frequency modulated by the voltage analog signals produced by the four transducers. The outputs from the VCOs were summed and frequency modulated the transmitter to form a conventional FM/FM system. The transmitting system, the transducers, signal conditioning, and excitation circuitry are shown as a block diagram in Figure 16.

A Microcom Corp. transmitter (T, Figure 17) with nominal frequency of 2.22 GHz and output power of 20 milliwatts was mounted in the waterscoop assembly in a cylindrical cavity to the rear of the antenna lead port. The antenna, designed at BRL, consisted of a phenolic cylinder threaded at the base for mounting in the waterscoop. The base of the antenna houses the mating connector to the transmitter. A semi-rigid, coaxial cable, which passes through the long axis of the pheonolic cylinder, is connected to fine wires that form the dipole radiating elements. These elements were bent to conform to the outside of the cylinder and ran parallel to its long axis. A small resistor, connected across the dipole, was used to broadband the antenna. The antenna was designed to be replaced on each shot through the recovery system.

The center frequencies of the Omnitek VCOs were 128, 192, 256, and 320 kHz with a ± 16 kHz deviation. The input voltage range for both the pressure and accelerometer modulated VCOs was 0 to 5 volts. The VCOs modulated by the strain transducers had a range of ± 2.5 volts, since both tension and compression were to be measured.

The PCB Piezotronics, Inc. accelerometer and pressure transducers (A and P, Figure 17), both piezoelectric devices, each contained a P-channel, Mosfet source follower in the transducer housing. These source followers functioned as impedance converters and provided a nominal 100-ohm output impedance. Excitation for these circuits was provided by a constant current source and the analog output signal was capacitive coupled to the VCO. Full scale output for these units was 5 volts. The pressure transducer contained a very rigid, acceleration-compensated, quartz element coupled to the source follower. This gage was mounted in the rear housing (Figure 12) with the gage diaphram exposed to the

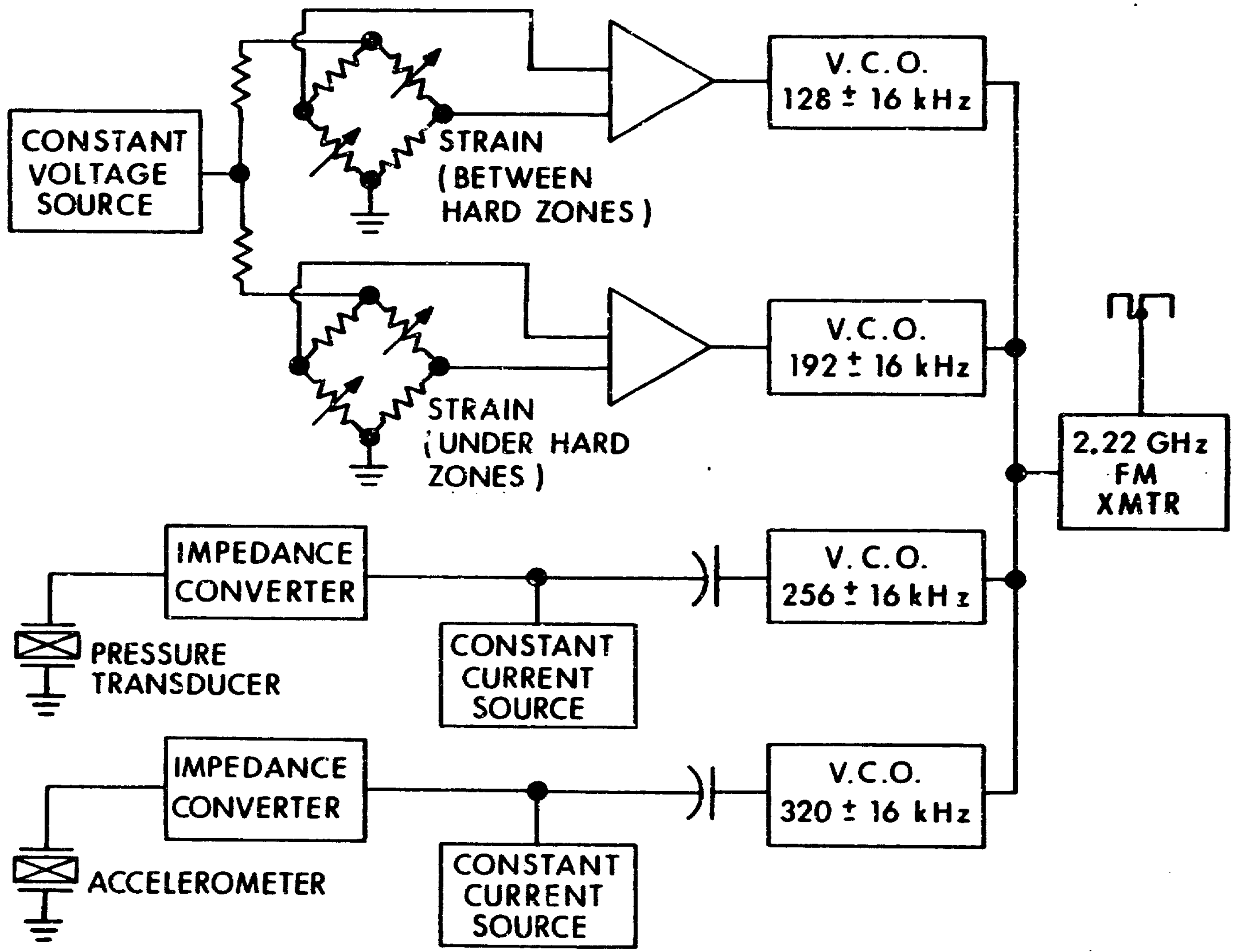


Figure 16. Block Diagram of CLGP Transmitting Circuit

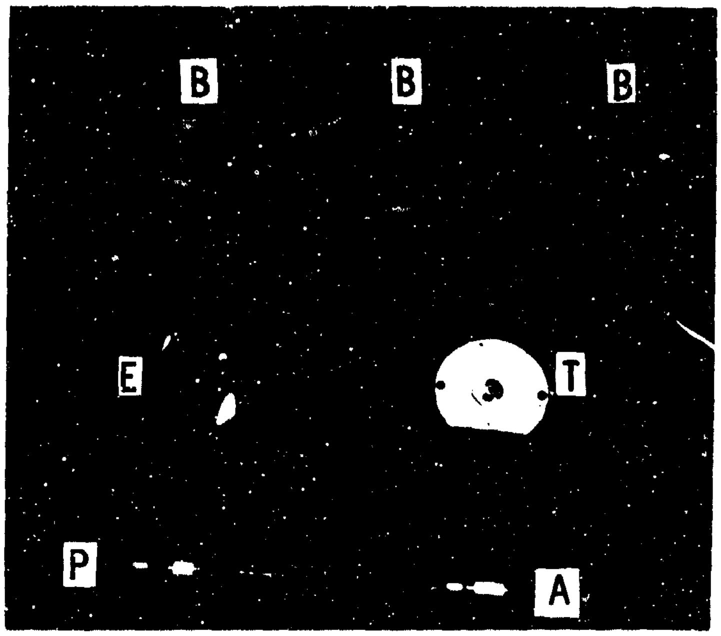


Figure 17. Transmitting Components and Transducers

propellant gases via a short silicone grease column. The accelerometer contained a seismic-mass-loaded quartz element coupled to the source follower. This transducer was mounted on the projectile long axis in the rear structure of the projectile in tandem with and forward of the pressure gage.

The strain measurements were made with conventional, resistive-type strain patches cemented to the inner wall of the projectile and connected in a bridge network. The strain patch elements formed the two active arms of the bridge and were located 180 degrees apart on the body surface to compensate for bending moments in the body. The patch orientation was such that they responded to the axial component of strain in the body. The inactive arms of the bridge consisted of similar strain patches which were isolated from the body strain by implanting them in the rear housing. The use of the same strain elements throughout the bridge network minimized thermal drift. Bridges for both strain circuits were excited by the same constant voltage source. The differential analog voltage output was amplified by an Omnitek, Inc. amplifier to make it compatible with the VCO.

The power supply for the transmitting system consisted of three, series-connected battery packs (B, Figure 17) each made up of six rechargeable nickel-cadmium cells. The current rating for these cells was 250 millampere-hours for a period of 10 hours. This provided about 45 minutes of operation of the transmitting system.

The electronics for the transmitting system (Figure 18) were packaged in a cylindrical module (E, Figure 17) and encapsulated in an epoxy compound. The module was mounted in a cavity in the waterscoop behind the transmitter. The battery packs were inserted in three, cylindrical cavities located 120 degrees apart in the base of the waterscoop. After all elements were assembled and connected, all voids within the structure were filled with an epoxy compound.

The proof projectile was designed to provide continuous measurement of linear acceleration at two locations during the in-tube travel. The instrumentation was contained in an aluminum cylinder that screwed into the rear of the waterscoop. Instrumentation for this transmitting system consisted of a dipole antenna, S-band transmitter, four VCOs, two accelerometers and eighteen nickel-cadmium cells that formed the power supply. The two accelerometers were contained within the instrumentation package. This minimized the wire runs and interfacing problems. The accelerometers each modulated two VCO's, one with a full scale input voltage of 0 to 5 volts and the other with an input voltage of 0 to 2.5 volts. This was done since the projectile was to be fired at various zone charge levels. At the lower zones, where the acceleration would be low, the 0- to 2.5-volt input VCO would provide better resolution than the 0- to 5-volt

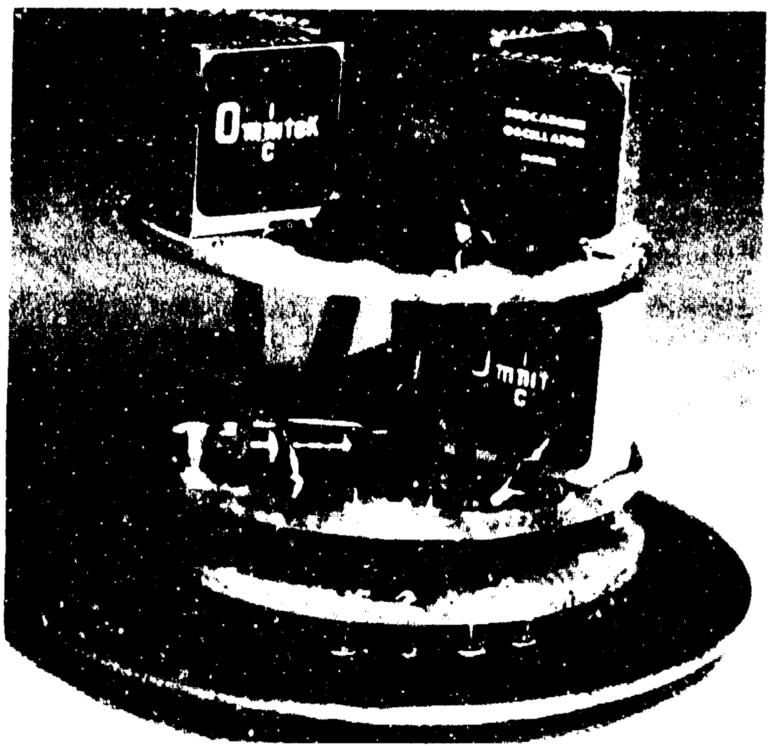


Figure 18. Electronics for Transmitting System

input VCO. The VCO frequencies were selected so if the higher resolution VCOs were overdriven, they would not interfer with the other channels. This was done by simply not using the next higher standard channel above the high resolution channels. A block diagram of the transmitting system is shown in Figure 19.

VII. SIGNAL RECEIVING AND PROCESSING

The output signals transmitted from the projectile during in-tube travel were received via a helical antenna located forward and to the left of the muzzle of the gun. It was found that precise positioning was not critical, except to be outside of extreme muzzle blast effects. Output from this antenna was fed into a down converter that translated a nominal 2.22-GHz signal to a nominal value of 235 MHz. This was done to avoid the large attenuation at the 2.22-GHz frequency caused by the 30.5 metres of coaxial cable between the antenna and the receiver. Signal level input to the receiver was then at -40 dbm.

The data discriminators used in the second detection process had an input bandwidth of 32 KHz and an output data filter bandwidth of 8 KHz. Stability of the RF transmitter during the in-bore travel of the projectile was monitored by the FM, direct-coupled, video output of the receiver. This signal was conditioned and filtered as an indication of the received RF frequency. The data output channels from the projectile were interrupted 350 ms prior to the event to insert staircase calibration steps. A block diagram of the receiving system is shown in Figure 20.

The data from this system were recorded in real time on an analog-to-digital recorder and simultaneously on analog, FM magnetic tape. These data, including the calibration staircase, were manipulated, scaled, and converted to engineering units under the control of a minicomputer. Six data channels are shown, but only those applicable to a particular round were recorded.

VIII. RESULTS

The results section covers both the initial testing of an instrumented CLGP and an in-house designed instrumented proof projectile. Each projectile was test fired to acquire acceleration data with additional onboard pressure and strain data being acquired on the CLGP.

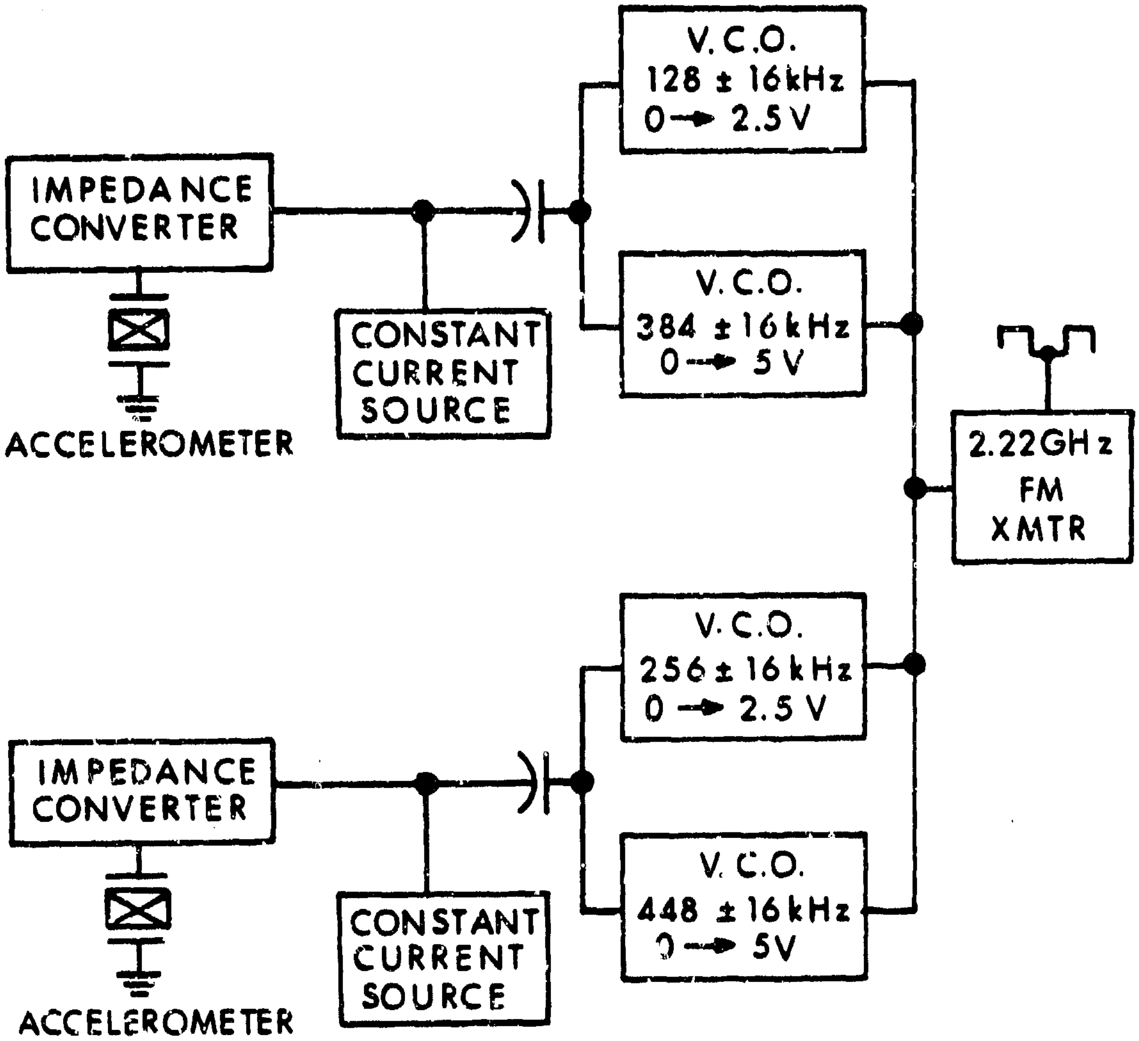


Figure 19. Block Diagram of Proof Projectile Transmitting System

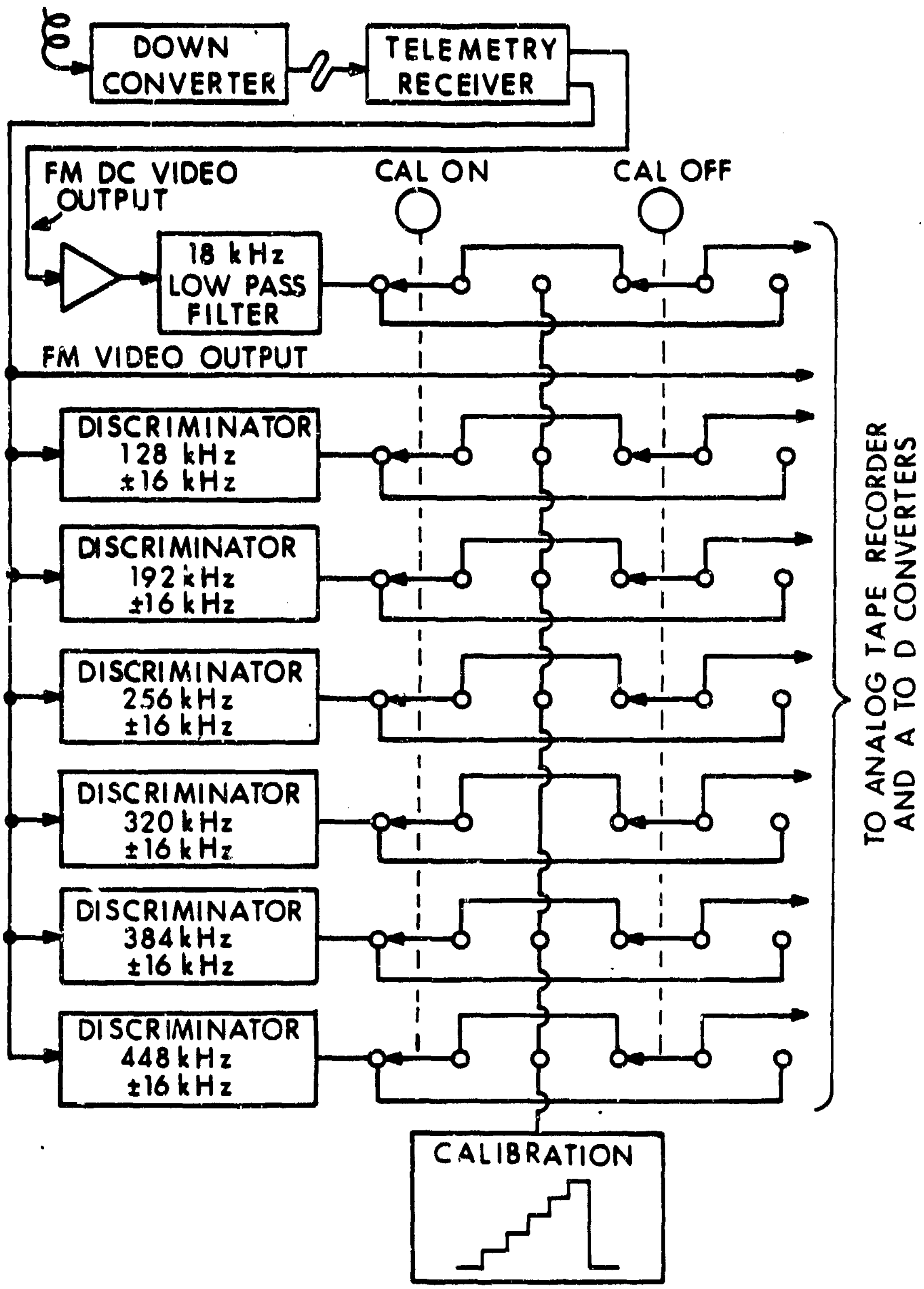


Figure 20. Block Diagram of Receiving System

A. Cannon Launched Guided Projectile Firings

The first test firing of the CLGP warhead using an M3A1, Zone 1 charge, was successful. Data were received during the entire in-tube travel and the projectile was recovered by the LCSRS without damage to either the projectile or the system. Acceleration, pressure, and strains as a function of time, are shown on Figures 21, 22, and 23.

In order to refire the projectile, a new antenna was installed in the scoop. It was not possible to replace the cylindrical plastic slip rotating and bourrelet bands by disassembling the projectile. Since the projectile was filled with epoxy that encapsulated the wires connecting the transmitter to the TM system, any attempt to dissemble the projectile would damage these wires. Therefore, existing slip and bourrelet bands were modified by cutting the bands at a 45-degree angle to make them expandable. This allowed the new slip and bourrelet bands to be easily installed in their respective mating grooves on the projectile.

The refitted projectile was test fired using a Zone 5, M3A1 charge and successfully recovered. The band pressure during engraving and in-tube travel was not sufficient to seal the 45-degree angle cut in the bands and provide sufficient obturation. Propelling gases forward of the projectile attenuated the radio telemetry signal below the receiver threshold. Therefore the data link with the projectile was lost early in the event.

The projectile was refitted with new slip bands which were glued at the 45-degree interface with an epoxy to enhance the sealing at this apparently weak joint. During the test firing using a Zone 7, M4A2 charge, the data link was lost early in the event. The CLGP warhead apparently failed intube resulting in extensive damage to both the projectile and the LCSRS. Although the failure mode was not determined, the repeated impulse loading of the two previous shots was believed to be a contributing factor.

The damage to the LCSRS was extensive. Bolts supporting the rail for a 15-metre length, 20 metres from the start of the trough were sheared. One of the 12-metre guide rails was split in two with extensive gouging of the trough in the vicinity of the split rail. While the LCSRS was being repaired, the backup proof projectile was instrumented for tests in the LCSRS.

B. Proof Projectile Firings

To requalify the LCSRS after repairing the damage done by the last CLGP projectile, eight firings were done with an uninstrumented proof projectile. These firings consisted of two Zone 1, M3A1; two Zone 3,

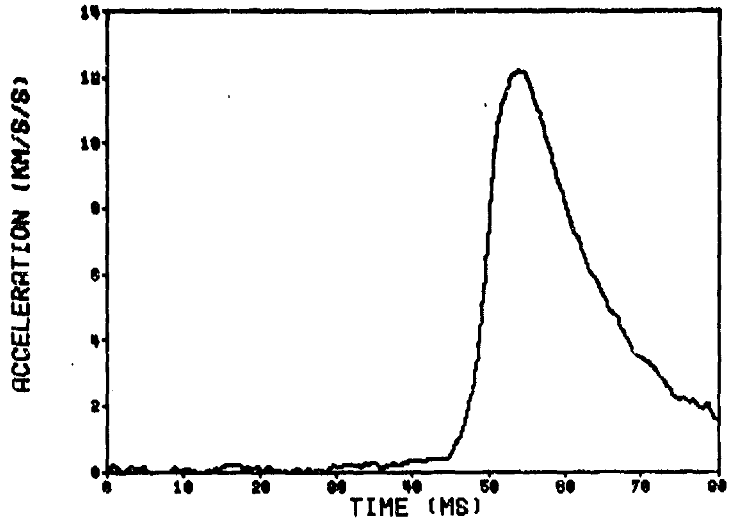


Figure 21. Onboard Acceleration for CLGP Warhead

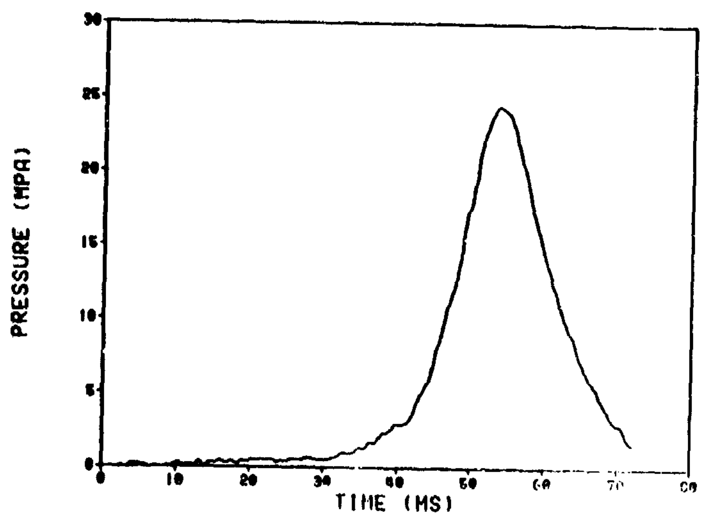


Figure 22. Onboard Base Pressure for CLGP Warhead

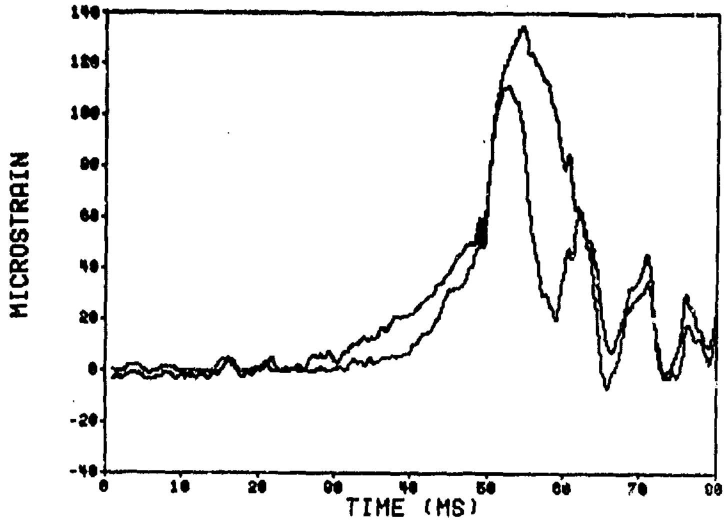


Figure 23. Onboard Strains for CLGP Warhead

M3A1, two Zone 5, M3A1; and two Zone 7, M4A2 charges. The projectile was subjected to pressures and accelerations ranging from 30 to 200 MPa and 15 to 80 km/s/s, respectively. Calculated muzzle velocities varied from 130 to 600 m/s. The successful completion of these initial tests on the repaired LCSRS enabled us to proceed with firing instrumented proof projectiles into the system.

The matrix for the instrumented test projectile consisted of five charge levels (Zone 1, M3A1; Zone 3, M3A1; Zone 5, M3A1; Zone 7, M4A2; and Zone 8, M119). Table 1 shows both calculated and experimental data as well as system parameters for the tests. For all firings, the pressure gage in the gun chamber and the accelerometer onboard the projectile were not changed. The recording system was adjusted to accommodate the large range of expected pressure and acceleration.

The gun chamber pressure and onboard acceleration as a function of time are shown in Figures 24 thru 28. In all plots, the pressure has already started to rise before the onboard accelerometer starts to respond. Since a minimum pressure level is needed before the projectile begins to move, this is expected. In all tests, the acceleration plots are an average of the two accelerometer gages onboard the projectile. The time scales on the various plots are referenced to the functioning of the M52A3B1 primer[5] used in a BRL modified firing lock. In all plots,

[5] *J. J. Rocchio, R. A. Hartman and N. J. Gerri, "An Electric Primer-Operated Firing Pin Actuator for Large Caliber Guns," ARBRL-MR-02897, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1979.* (AD #A069109)

TABLE 1. TEST DATA

PROPELLANT CHARGE	ZONE	PROJECTILE TYPE/WT(kg)	EXPERIMENTAL DATA BREECH PRESSURE (MPa)	EXPERIMENTAL DATA ACCELERATION (km/s/s)	CALCULATED DATA ACCELERATION (km/s/s)
M3A1	1		33.6	10.8	12.0
M3A1	3	BRL Proof Projectile	57.8	18.8	20.5
M3A1	5	53.5	112.6	36.7	39.6
M4A2	7		197.5	63.4	67.2
M119	8		232.6	69.3	77.0

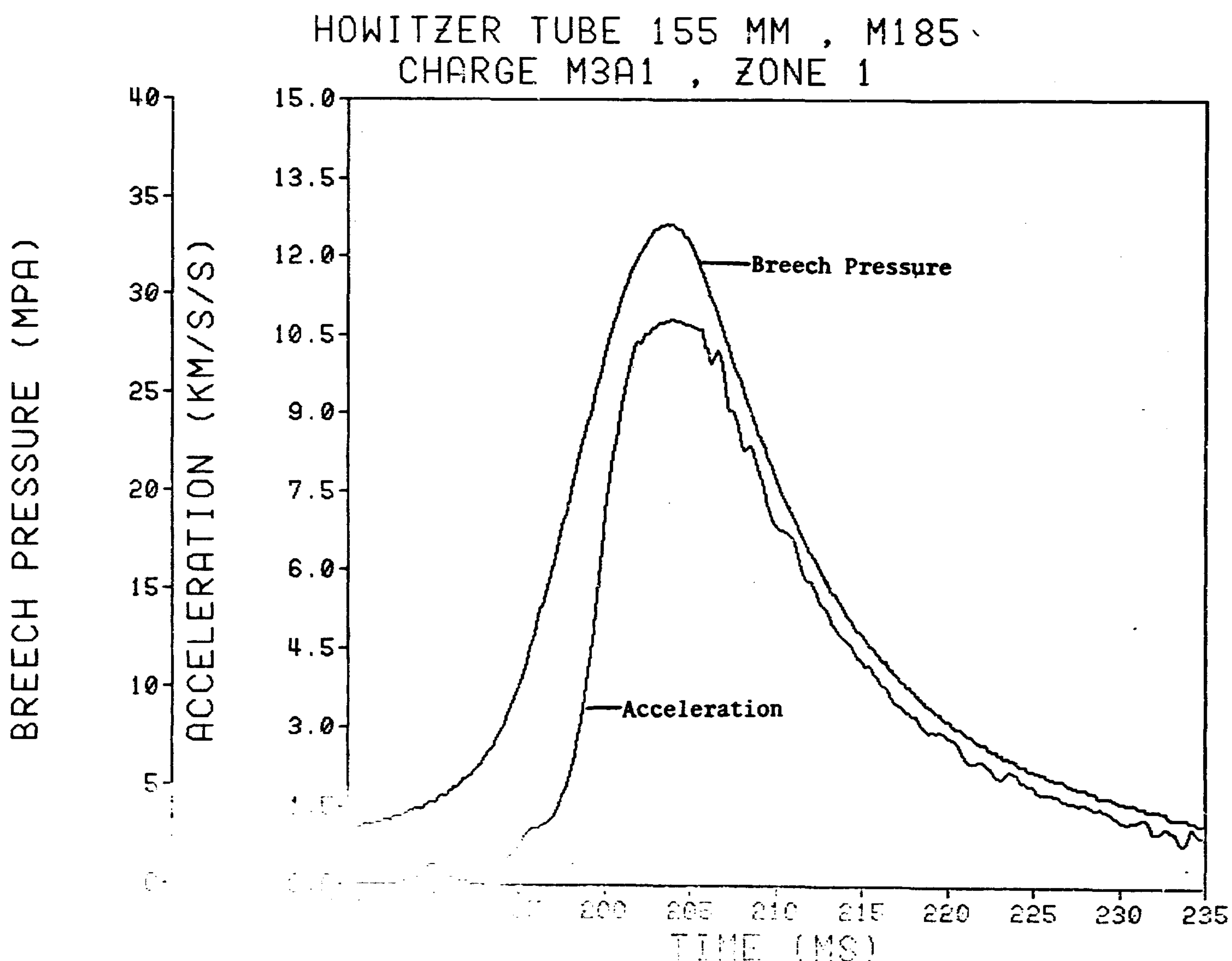


Figure 24. Gun Chamber Pressure and Onboard Acceleration Versus Time - Proof Projectile, Zone 1

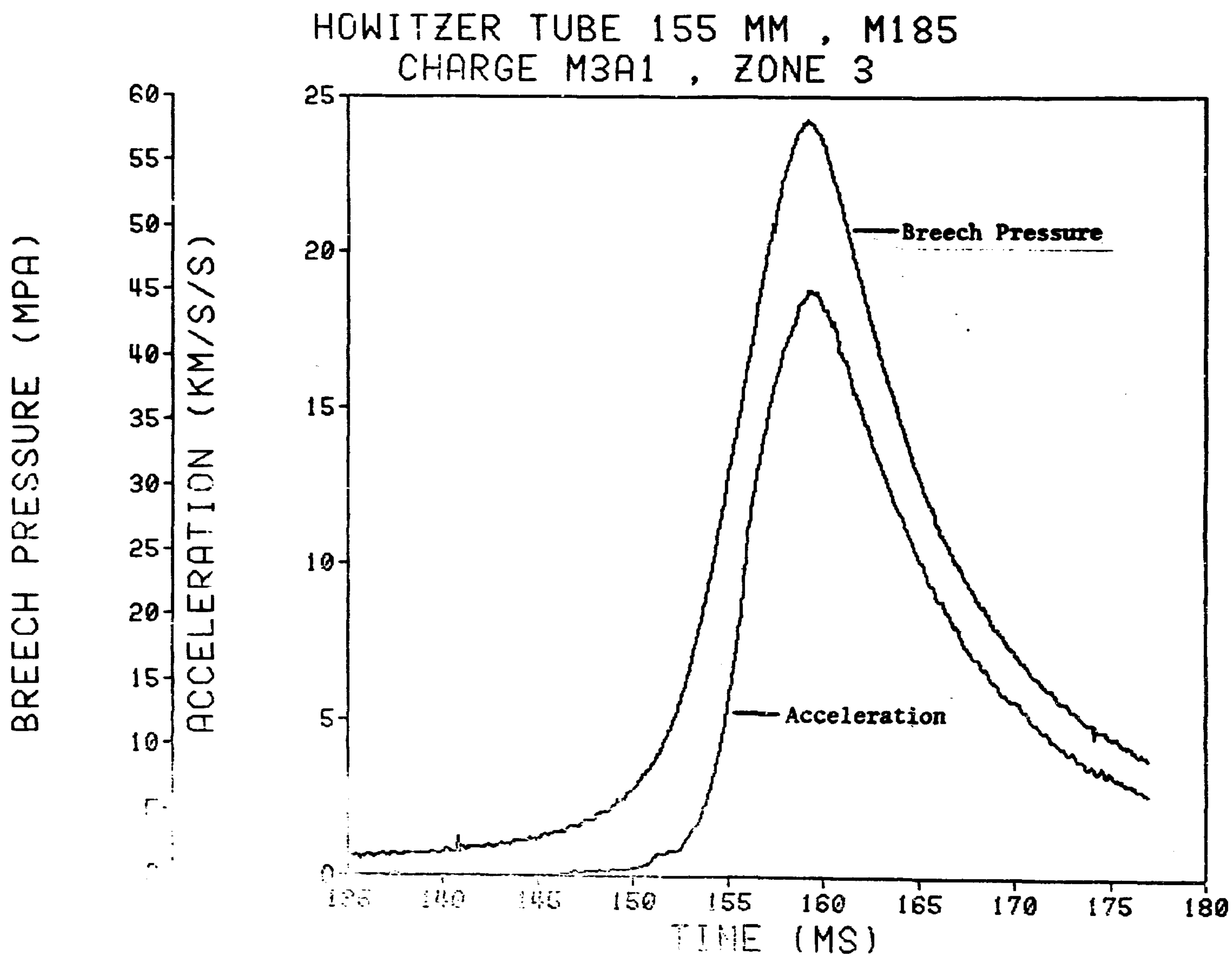


Figure 25. Gun Chamber Pressure and Onboard Acceleration Versus Time - Proof Projectile, Zone 3

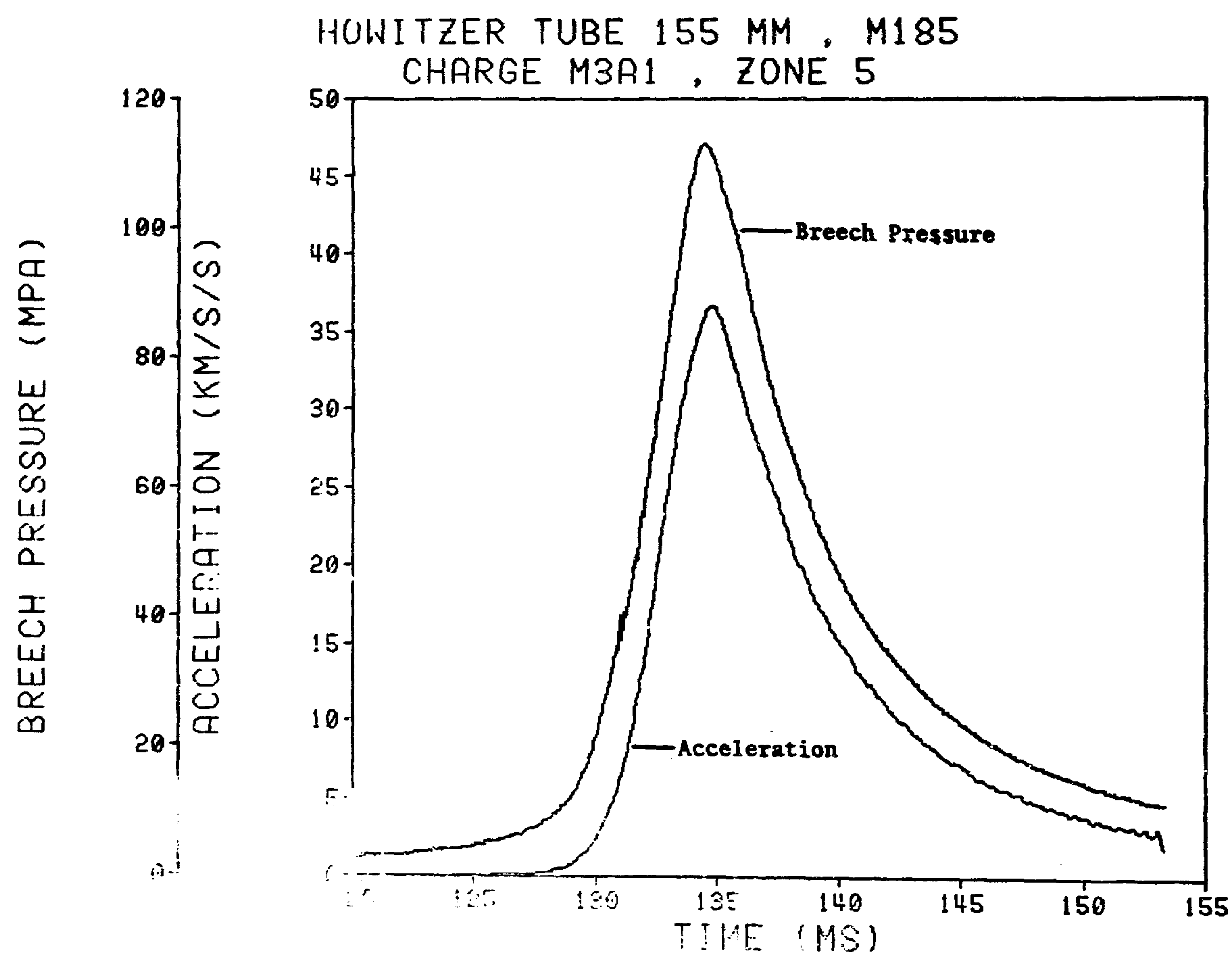


Figure 26. Gun Chamber Pressure and Onboard Acceleration Versus Time - Proof Projectile, Zone 5

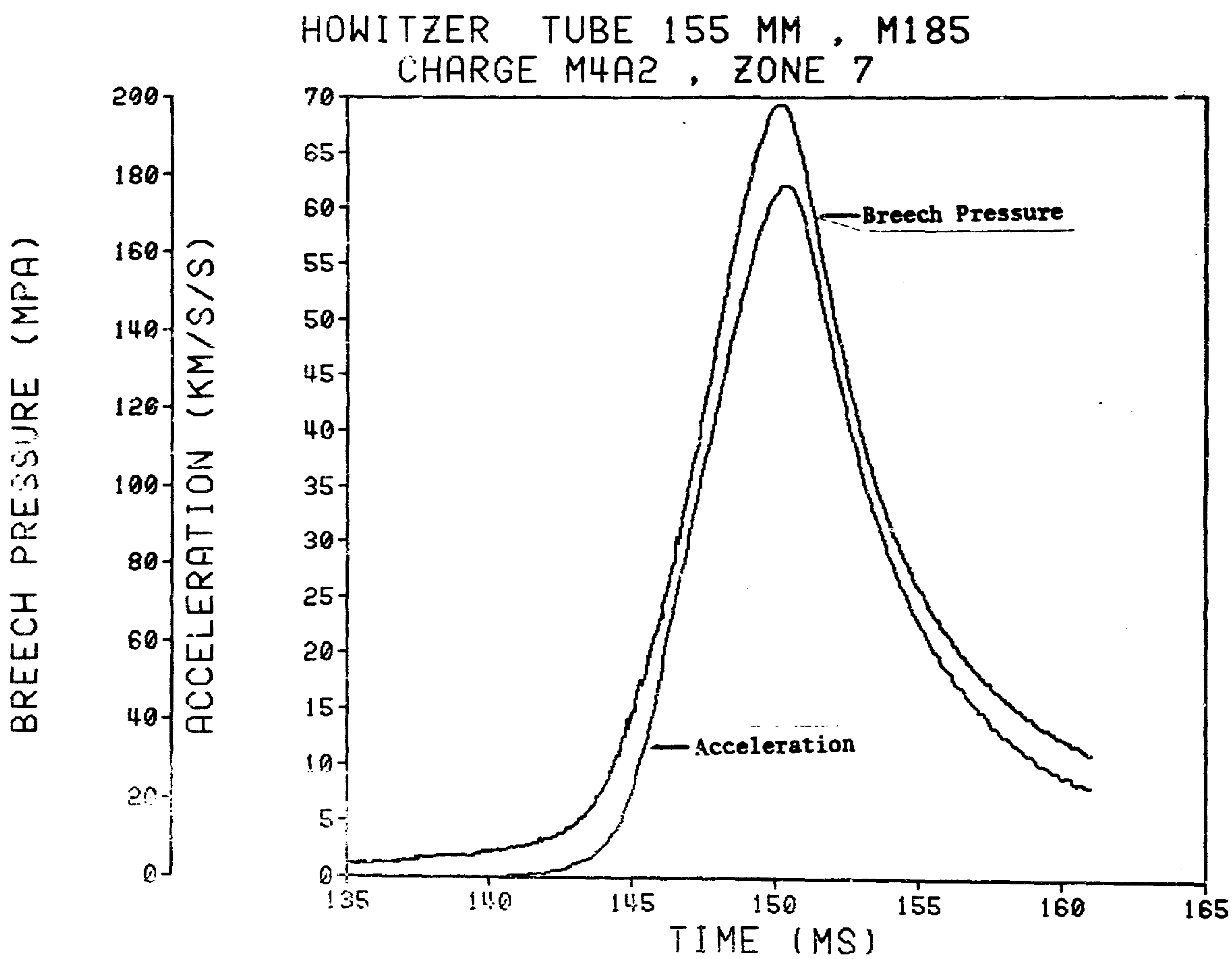


Figure 27. Gun Chamber Pressure and Onboard Acceleration Versus Time - Proof Projectile, Zone 7

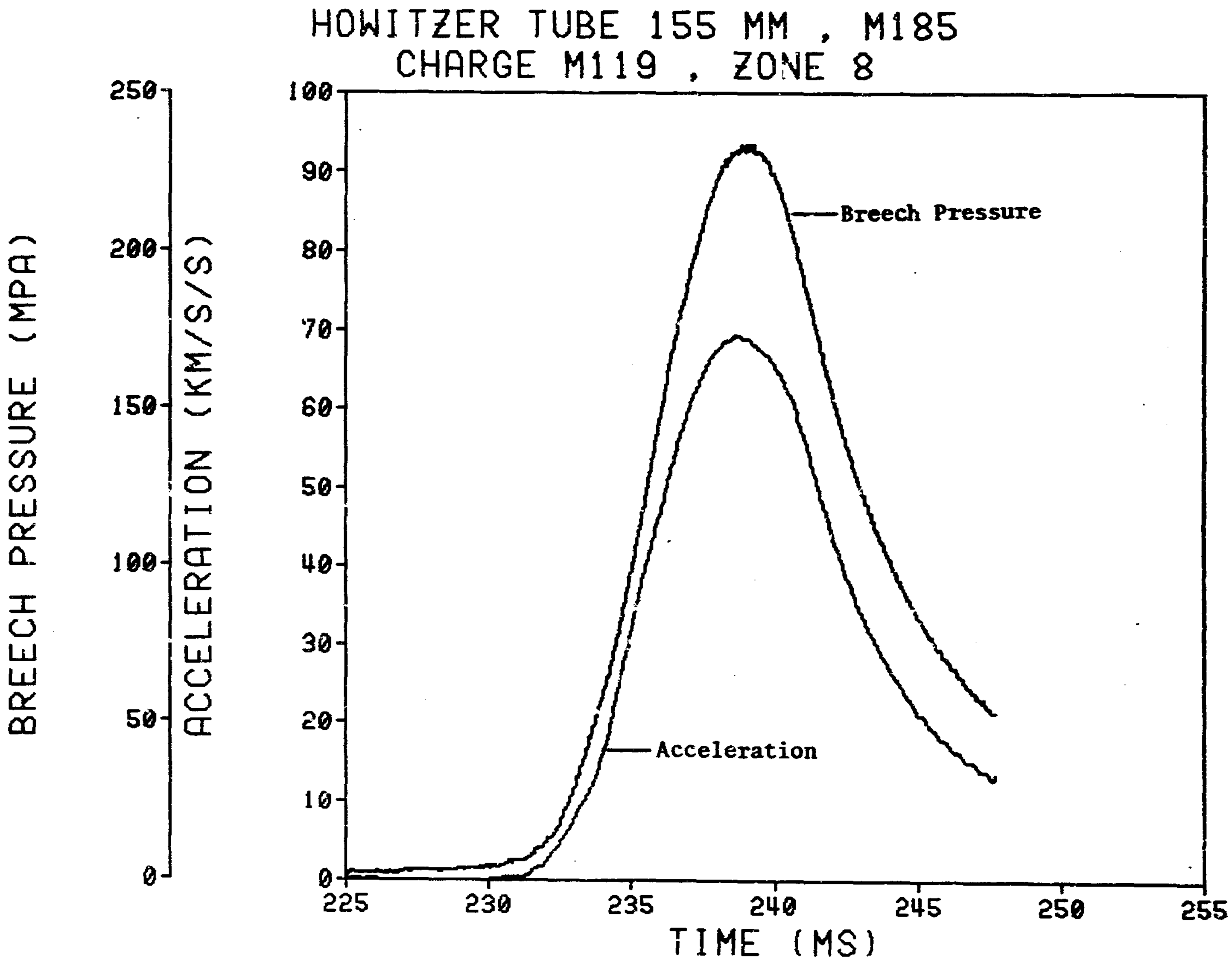


Figure 28. Gun Chamber Pressure and Onboard Acceleration Versus Time - Proof Projectile, Zone 8

both the pressure and acceleration data were smoothed. The trailing edge of the acceleration plot represents approximate muzzle exit.

Projectile acceleration was calculated using Newton's second law of motion and the measured breech pressure. From Newton's second law of motion,

$$F = m \cdot a \tag{1}$$

where F = Force acting on the projectile
m = Mass of the projectile
and a = Acceleration of the projectile.

The forces acting on the projectile in a gun firing are given by

$$F = (P_b - P_f)A \tag{2}$$

where P_b = Pressure acting on base of the projectile

P_f = Engraving and frictional pressure

and A = Cross-sectional area of the bore.

therefore, $F = m \cdot a = (P_b - P_f)A$ and $m = \frac{w}{g}$

or $$a = g\,\frac{(P_b - P_f)A}{w} \tag{3}$$

where w = Projectile weight

and g = Gravitational constant.

From the La Grangian correction, base pressure (P_b) can be reasonably calculated from the measured breech pressure (P) by the expression,

$$P_b = \frac{P}{1 + \frac{c}{2w}} \tag{4}$$

where c = Propellant weight

w = Projectile weight.

Assuming no engraving and frictional losses (P_f = o), the acceleration calculated from combining Equations 3 and 4 is given by

$$a = \frac{g \cdot P \cdot A}{w\,(1 + \frac{c}{2w})} \tag{5}$$

Since our equation assumed $P_f = 0$, calculated acceleration must always be larger than onboard measured acceleration; otherwise the accelerometer is inaccurate. In all test firings, the peak recorded acceleration was reasonable and was not larger than that calculated from peak breech pressure.

Another method of determining the relative accuracy of the onboard acceleration is illustrated in Figures 29 thru 33. Here the measured onboard accelerometer data are plotted against time. Also plotted are the velocity (integrated acceleration) and displacement (double integrated acceleration). Displacement was approximately 4.8 metres at loss of signal for Zones 1, 5, 7 and 8. Zone 3 displacement was 3.2 metres, an anomaly, probably caused by an early loss of the accelerometre signal. Actual intube gun displacement is approximately five metres. The consistency of the measured values across a wide range of accelerations indicates the accelerometer gage is performing in an acceptable manner.

Another technique for demonstrating the wide range of accelerations is shown in Figure 34. On a common axis is plotted each of the accelerations versus their double-integrated accelerometer displacement. Accelerations ranged from 11 to 70 km/s/s.

IX. CONCLUSIONS

Much remains to be done to prove the real potential of this research tool, not only in the extension of firing tests to encompass the total spectrum of calibers for which the recovery system was designed, but also in greatly expanding the instrumentation capabilities. Although the recovery system itself is considered a very valuable asset, it represents but one link in the data acquisition process. Useful measurements of the behavior of the projectile during in-bore travel are a requirement, but equally necessary are measurements to describe the projectile behavior during the recovery phase, so that the effect of that environment is not deleterious to the components being tested. Efforts concerning all aspects of the total data acquisition process are being addressed as speedily as possible.

Initial tests with onboard accelerometers was successful in that data was transmitted for a large range of zones for the entire in-bore cycle. Refinements in the method of calibrating the accelerometers are requirements for the transmitted data to accurately reflect the dynamic conditions onboard the projectile.

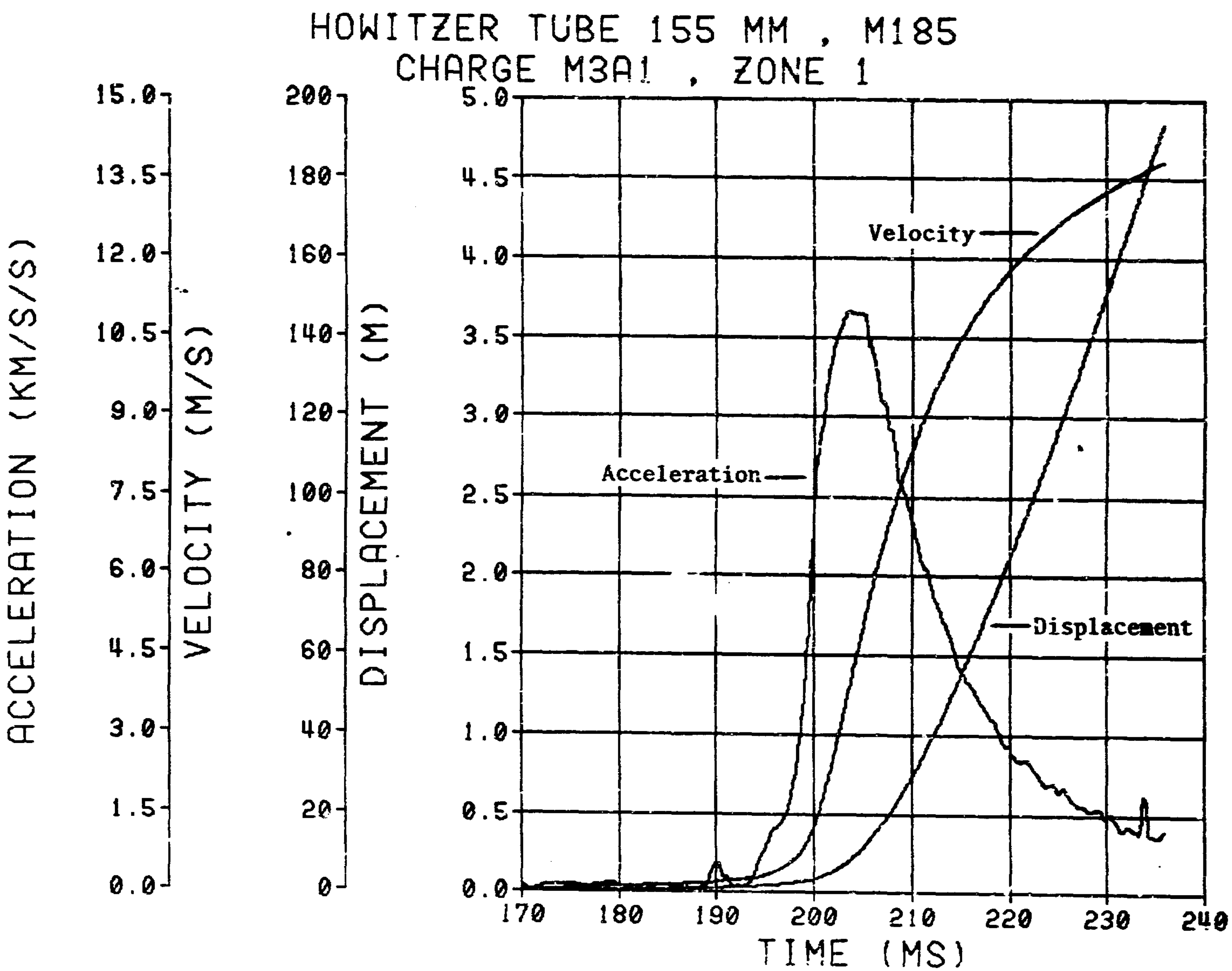


Figure 29. Acceleration, Velocity, and Displacement Versus Time - Procf Projectile, Zone 1

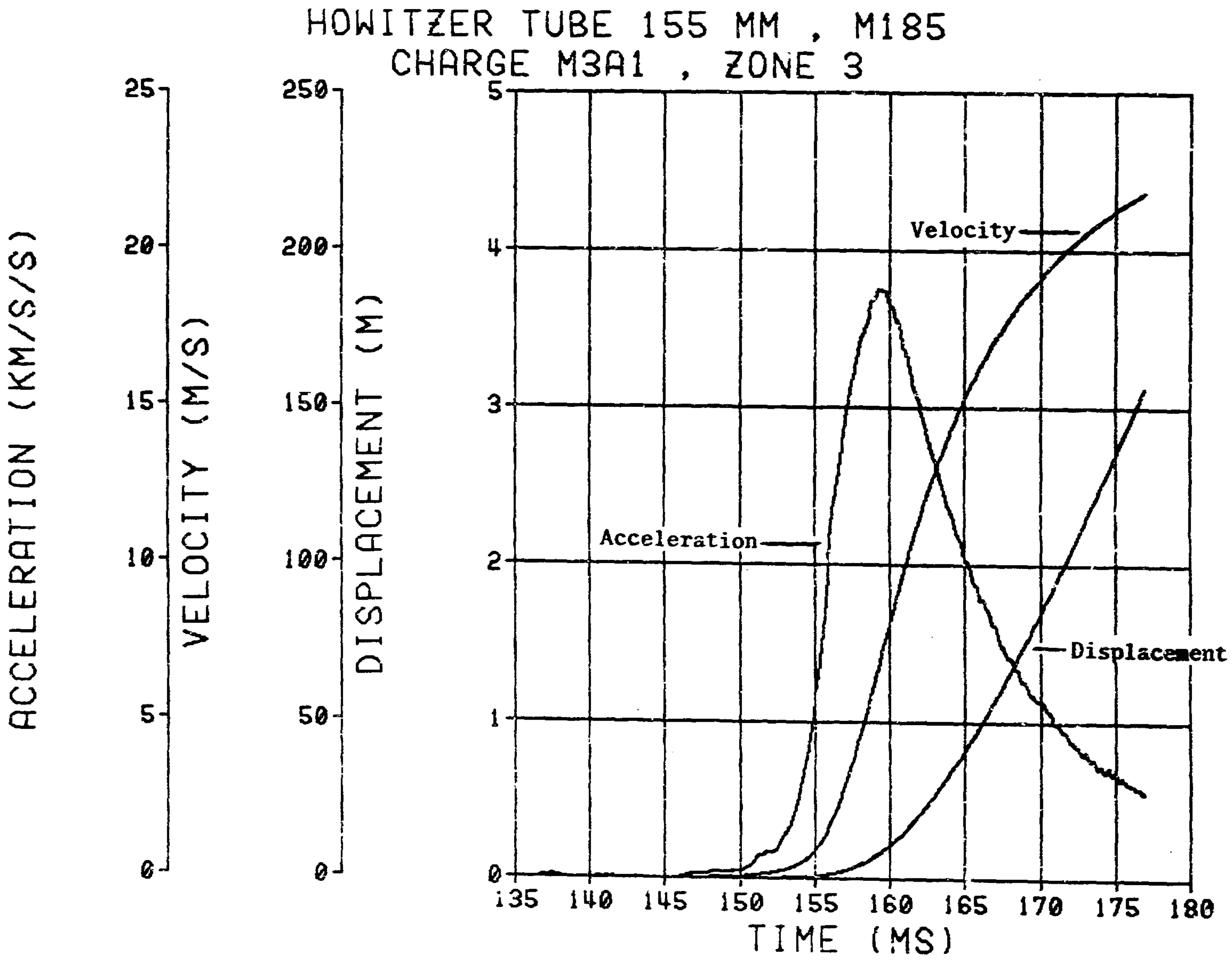


Figure 30. Acceleration, Velocity, and Displacement Versus Time - Proof Projectile, Zone 3

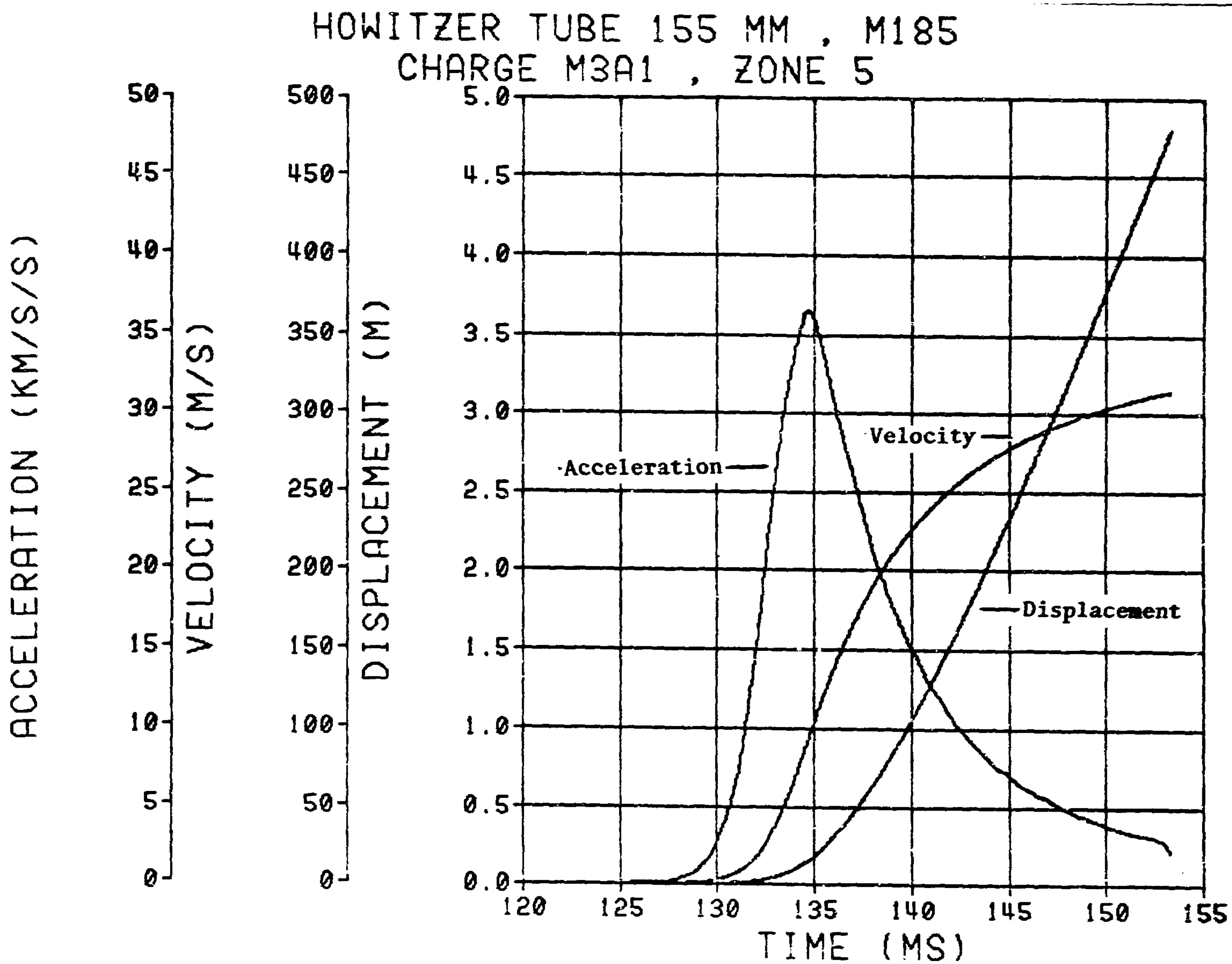


Figure 31. Acceleration, Velocity, and Displacement Versus Time - Proof Projectile, Zone 5

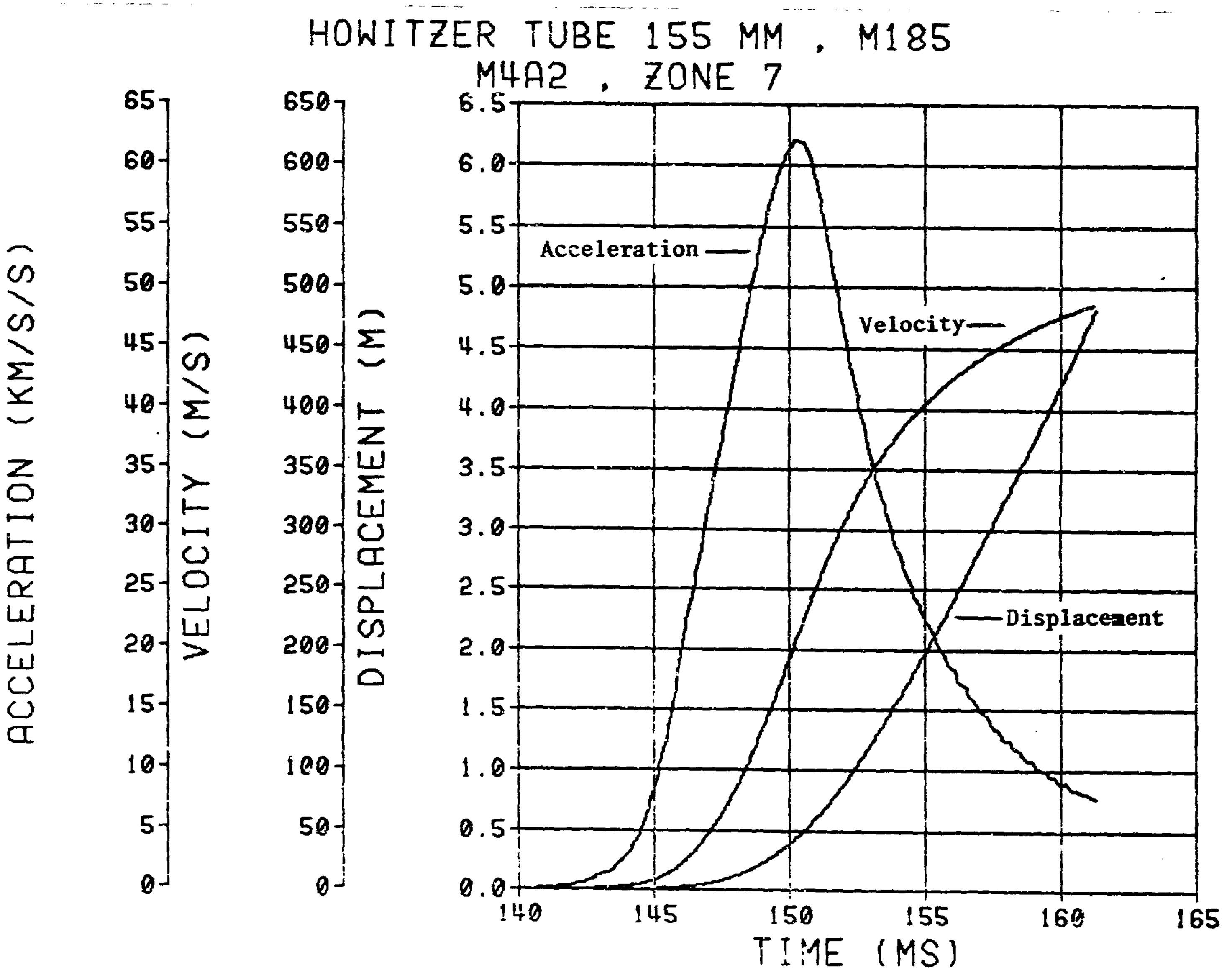


Figure 32. Acceleration, Velocity, and Displacement Versus Time - Proof Projectile, Zone 7

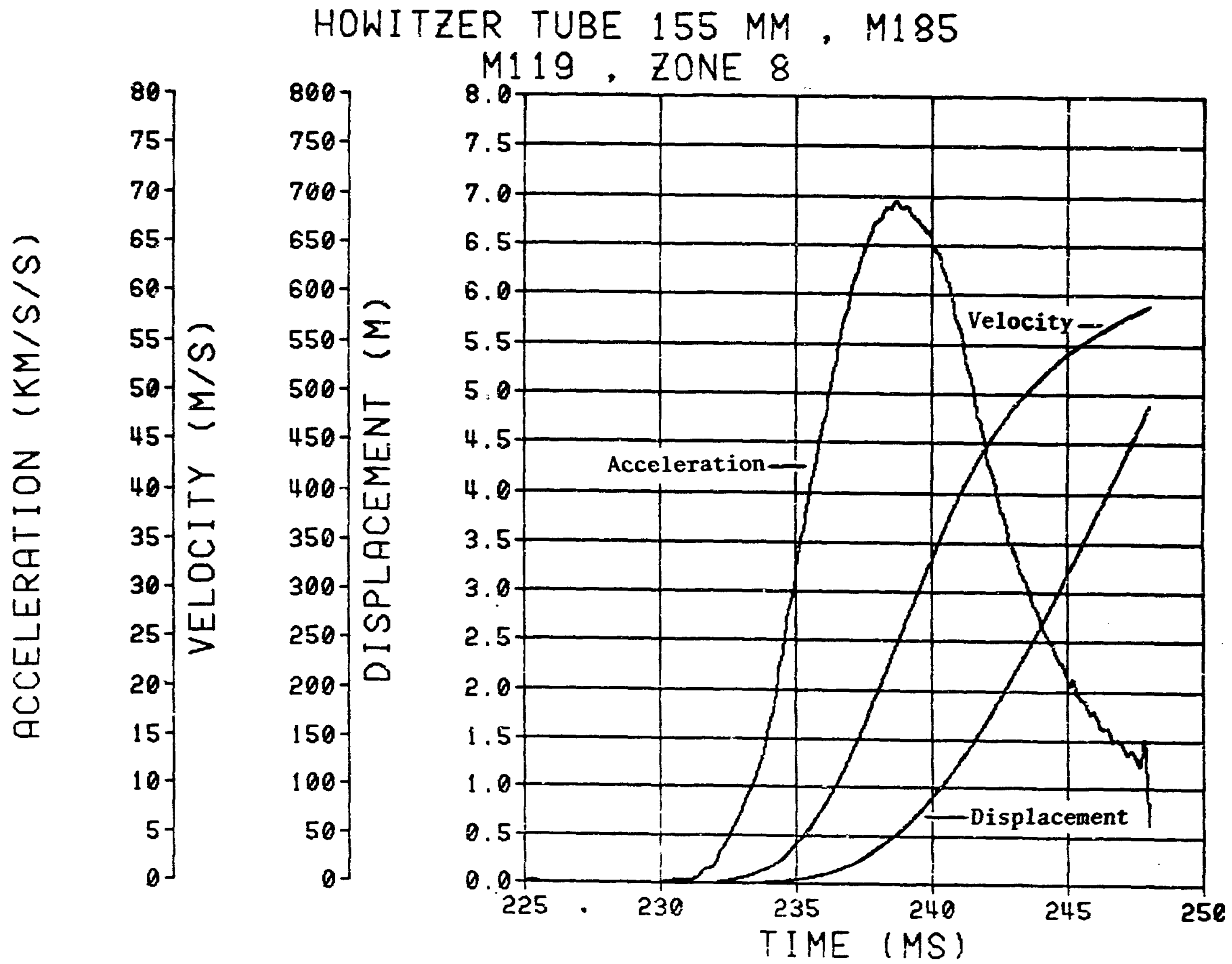


Figure 33. Acceleration, Velocity, and Displacement Versus Time - Proof Projectile, Zone 8

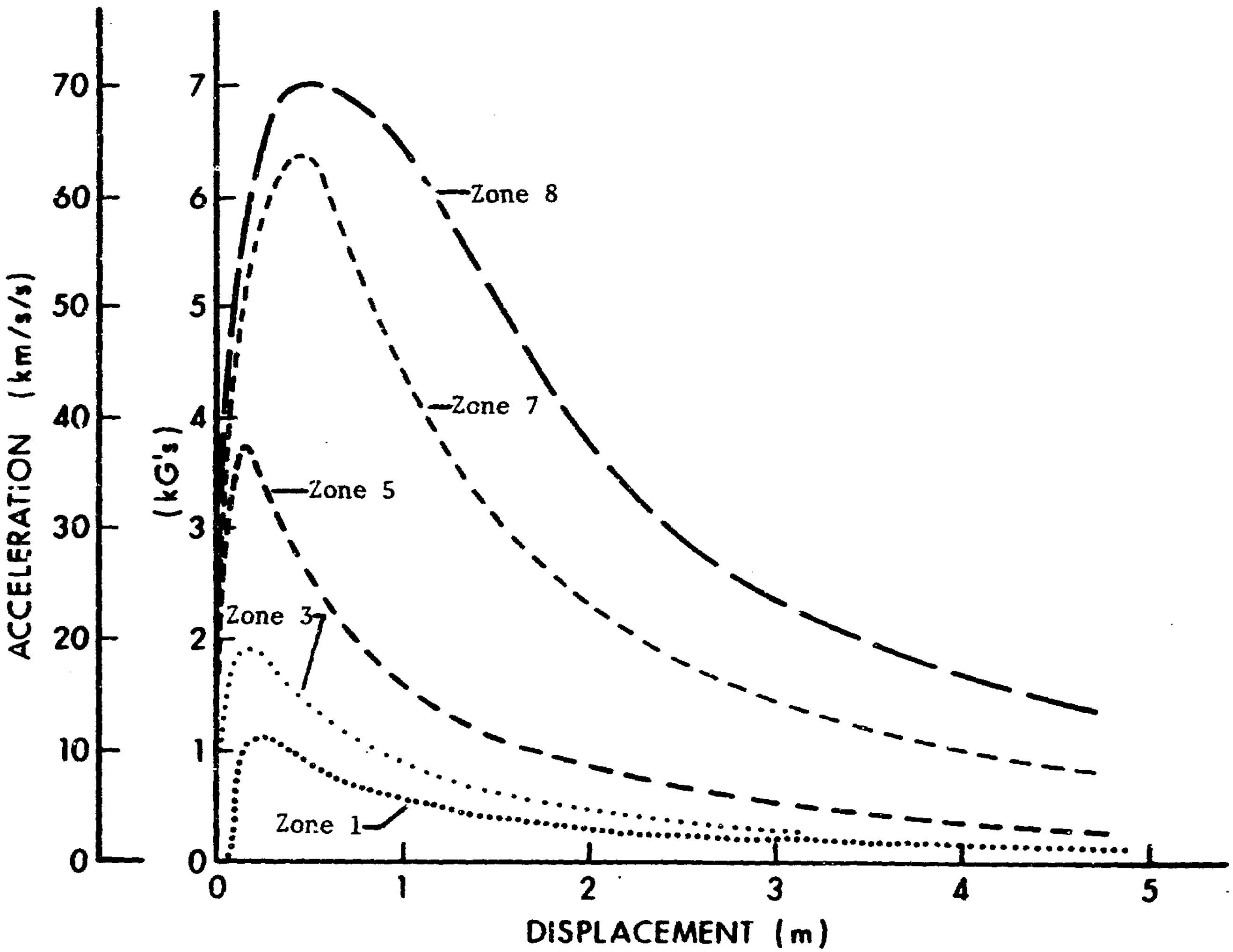


Figure 34. Acceleration Versus Displacement for Proof Projectile

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REFERENCES

1. L.D. Wright, "An Investigation of High "g" Launch, Soft-Recovery Test Facilities," Tank Systems Laboratory Technical Report No. RE-TR-71-12, US Army Weapons Command, R&D Directorate, Rock Island, Illinois, March 1973.

2. P.G. Baer, "A Digital Computer Analysis of a 155-mm Soft Recovery System," BRL Report No. 1634, February 1973.

3. E.J. Halcin, J.A. Pratt, "Design of a Large Caliber Soft-Recovery System for the Ballistic Research Laboratories," BRL Contractor Report No. 308, prepared by Honeywell, Inc., August 1976.

4. C.R. Hargraves, "Metallurgical Control of Fragmentation, Phase II," BRL Contractor Report No. 350, prepared by Honeywell, Inc., September 1977.

5. J.J. Rocchio, R.A. Hartman and N.J. Gerri, "An Electric Primer-Operated Firing Pin Actuator for Large Caliber Guns," ARBRL-MR-02897, USA ARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1979.

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